

AUTOMATION SYSTEMS FOR HIGHWAY ORGANIZATIONS

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AUTOMATION SYSTEMS FOR HIGHWAY ORGANIZATIONS

Proceedings of the Western Summer Meeting sponsored by the Highway Research Board and co-sponsored by the Texas Highway Department and the College of Engineering, University of Texas at Austin, August 16-18, 1971, Austin, Texas

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11	Transportation Administration
21	Photogrammetry
22	Highway Design
25	Pavement Design
27	Bridge Design
40	Maintenance, General
53	Traffic Control and Operations
81	Urban Transportation Administration

Special Report 128 Highway Research Board



DIVISION OF ENGINEERING • NATIONAL RESEARCH COUNCIL

National Academy of Sciences - National Academy of Engineering

Washington, D.C.

1972

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ISBN 0-309-01997-4

Library of Congress Catalog Card No. 72-80756

Price: \$3.80

Available from

Highway Research Board

National Academy of Sciences

2101 Constitution Avenue, N.W.

Washington, D. C. 20418

CONTENTS

FOREWORD.	v
Part I: Automated Systems	
WHAT IS AN AUTOMATED SYSTEM FOR HIGHWAYS? W. A. Bulley.	1
WHY AUTOMATION SYSTEMS IN HIGHWAY DEPARTMENTS? Wesley J. Burmeister.	6
WHY DO WE NEED COORDINATION OF AUTOMATION SYSTEMS? Ralph D. Johnson.	9
COMPUTER APPLICATIONS MUST BE MANAGED Marvin E. Hermanson.	18
Part II: Highway Design Systems	
ENGINEERING SYSTEMS: AN OVERVIEW W. A. Wilson, Jr.	23
AUTOMATED ROAD DESIGN Larry G. Walker.	28
TEXAS HYDRAULIC SYSTEM Dwight Reagan.	36
AUTOMATION IN PAVEMENT DESIGN AND MANAGEMENT SYSTEMS W. Ronald Hudson, Ramesh K. Kher, and B. Frank McCullough.	40
PILOT STUDY OF THE BRIDGE ENGINEERING SUBSYSTEM OF TIES John G. Ruby and Richard J. Posthauer.	54
SYSTEMS FOR BID ANALYSIS, GUARDRAIL LOCATIONS, CONSTRUCTION SCHEDULING, AND ESTIMATING EARTHWORK QUANTITIES W. A. Wilson, Jr.	59
Part III: Administrative Management Systems	
ADMINISTRATIVE MANAGEMENT INFORMATION SYSTEMS Theodore E. Stephenson, Jr.	65
DEVELOPMENT OF FINANCIAL MANAGEMENT INFORMATION SYSTEMS Benton B. Warder.	72

AUTOMATION ACCOUNTING, BUDGETING, PERSONNEL, AND OTHER INTERNAL ADMINISTRATIVE ACTIVITIES	
Roger R. Shipley	77
William G. Ainsley	79
AUTOMATION AND ITS COMMUNICATIONS VACUUM	
Jack Stanton.	81
ROADBLOCKS TO EFFECTIVE MANAGEMENT OF AUTOMATION	
Marvin E. Hermanson	83
J. T. Kassel	83
Eugene Bardach	85
 Part IV: Highway Operations Systems	
AUTOMATION IN TRAFFIC OPERATIONS AND HIGHWAY MAINTENANCE	
Mathew J. Betz	89
AUTOMATIC TRAFFIC OPERATIONS AND MAINTENANCE IN THE PORT OF NEW YORK AUTHORITY	
Alan T. Gonseth.	93
THE LOS ANGELES 42-MILE SURVEILLANCE AND CONTROL PROJECT	
Alvord C. Estep.	96
MAINTENANCE MANAGEMENT IN OREGON	
Tom Edwards.	100
 Part V: Transportation Information Planning Systems	
PLANNING INFORMATION SYSTEMS: AN OVERVIEW	
Robert E. Barraclough	105
DEVELOPMENT OF A DATA BASE FOR BIENNIAL NATIONAL TRANSPORTATION NEEDS REPORTING	
Alan E. Pisarski	111
INFORMATION SYSTEMS RELATED TO HIGHWAY PLANNING	
Roy T. Messer.	113
PROGRAMS OF THE U.S. BUREAU OF THE CENSUS RELATED TO HIGHWAY PLANNING	
Donald E. Church	116
DEVELOPING A STATEWIDE HIGHWAY DATA BASE IN TEXAS	
J. E. Wright	120
 Part VI: Summary	
WHERE DO WE GO FROM HERE WITH AUTOMATION SYSTEMS?	
C. L. Miller	125
SPONSORSHIP OF THIS SPECIAL REPORT.	
	128

FOREWORD

This Special Report contains the technical papers and prepared discussions presented at the Highway Research Board's Summer Meeting, which was held August 16-18, 1971, at Austin, Texas. The purpose of the symposium was to stimulate interest in and advance the use of computer-based automation systems for highway organizations, and emphasis was on establishing communication among various interested disciplines. The meeting was structured to present and discuss only those systems currently being used or in the process of being implemented. It did not attempt to cover all of the systems now being successfully applied by highway organizations.

The papers fall into 5 general categories. The first group of papers introduces the subject of automation to those responsible for administrative and managerial decisions in the development of systems. These papers explore the advantages of computer applications and offer some advice on their coordination and management.

The second group of papers reports successful applications of computer techniques to the design of roads, bridges, pavements, hydraulic systems, and other activities related to the preparation of plans and contractual documents. These and numerous other systems are available to the design engineer.

The development of administrative management information systems is addressed in the third group of papers. Attention is focused on financial and personnel management information systems and problems associated with effective management of automation.

The fourth group of papers on highway operations provide information on the application of automation techniques in traffic operations and highway maintenance. Subjects include freeway surveillance and control; automatic traffic operations and maintenance at restricted facilities such as bridges, tunnels, and terminals; and statewide maintenance management.

The last group of papers examines the application of computers and computer procedures to transportation planning, planning of transportation information systems, data collection, and development and use of data bases and programs.

The final paper discusses the future of automation systems.

Several of the papers in this Special Report discuss the Total Integrated Engineering System (TIES). The Federal Highway Administration has suggested that the following note be included in this Special Report.

An FHWA administrative decision has been made to discontinue support of the concept of a Total Integrated Engineering System (TIES); however, the development of several subsystems will continue.

PART I

AUTOMATED SYSTEMS

WHAT IS AN AUTOMATED SYSTEM FOR HIGHWAYS?

W. A. Bulley, Washington State Department of Highways

During the past 20 years, automation has become one of the major tools used in highway operations. Most highway departments recognize that automation provides more than a means of handling routine accounting and engineering tasks. Automation also significantly affects methods of management and the organization and conduct of business. Although the use of automation has not proved to be the solution to all management problems, those who take advantage of advanced data processing and communication techniques will benefit greatly.

It is easily forgotten that, by means of automation, we do many things today that we could not even attempt to do just a few years ago. For the engineer, automation has changed the rules of what is possible and what is practical. Through simulation processes, we have been able to develop additional design alternatives that just a few years ago might have been considered too time-consuming or costly to investigate. We know from experience, for example, how automation can contribute to the design and construction of bridges.

Many highway operations have been affected by automation. Most accounting functions are wholly or in part dependent on data processing results, and many complex engineering functions effectively use automation techniques. Other areas of operation that are traditionally slow in adopting new ideas, such as highway maintenance management, are beginning to demand their share of the automation dollar. It has been estimated that in Washington the development and implementation of a maintenance work plan, based on established standards, saved the state 311,974 man-hours and \$1,762,700 during the first year it was used. The development of these standards, as well as the timely reporting of performance, simply could not have been achieved without the availability of high-speed computers. Highway maintenance personnel feel that they have barely scratched the surface in this area, and these plans are being further implemented and refined.

Many of the first attempts at automation were made by highway planners. Currently, some of the most useful benefits of automation are in planning-related areas. Washington, along with many other states, uses the computer to develop and maintain PERT or critical path networks of the myriad of activities, constraints, and priorities in its highway construction program. The Washington Automated Control System (WACS) has been in use for about 4 years. This computer-based system is one that uses the critical path method for scheduling precontract engineering and related activities for the state's highway construction program. The objectives for such a system are the scheduling and control of engineering activities at the district level and the coordination of those activities among the several headquarters units that are responsible for testing of materials, design checking, financing, and advertising of contracts. The system provides for the generation of an initial critical path schedule for review, revision, and further revision by all of the affected organizational units resulting in a schedule that is mutually satisfactory. This system can be cycled whenever desired to produce "hot" lists and other monitoring reports.

The WAC system provides mutually approved schedules for monitoring progress and also provides information retrieval for planning work loads. For control, the system provides for changing activities and events so that the remainder of the schedule is both current and realistic. The initial function of the critical path method was to

provide management with a review procedure that would assist in improving and accelerating methods of operation on a single project. We can do this with as many as 500 projects. We can compare them with one another, we can include a time span up to 6 years, and each project can have as many as 1,000 activities. The system provides exception batch reporting in the form of the "hot" lists and also provides for immediate inquiry, via video terminals, from the on-line data base.

By using a single system, diverse organizations in various locations can make decisions based on the same facts. Top management uses the same facts, available in the same time period, as does the man in the field. The system highlights the exceptional condition—the schedule conflict or the missed commitment—rather than the routine one. It meets, to some degree, all four of the following criteria that I think are necessary for a good automation system:

1. It is economical;
2. It produces information faster than does the manual system;
3. It is more accurate than a fragmented manual system; and
4. It performs work much too complex to be done by human beings.

AUTOMATION CHANGES IN THE 1960s

Everyone who has been closely involved in highway automation activities has felt at times that the pace of change is too slow. Yet when we look over a long period of time, such as the past 20 years, we find that remarkable and fundamental changes have occurred.

At first computers were primarily used to speed up the accounting process—budgeting, accounting, and payroll work. A few pioneers, however, began to use the computer for engineering tasks. This use has expanded and become accepted to the extent that most large engineering organizations now consider the computer an indispensable tool. Several new management techniques involving the use of computers were developed in the 1960s, and highway departments have now had the opportunity to evaluate the results of these techniques and to determine their validity. Labor reporting systems, scheduling and control techniques for all phases of transportation-oriented programs, and many other innovations involving automation are being analyzed.

We have learned that management techniques should be designed with sufficient flexibility to permit modification in order to respond to changing requirements or demands. At the same time, the development of these programs must be in accordance with carefully specified plans. Today we can see the implementation of ideas that were conceived during the past 15 years and that contain at least some elements of totally automated design and administration of a highway system. We also learned during the 1960s that a highway system cannot be entirely administered through automation. No one has yet automated the ingredient of management judgment.

Environmental factors are essential elements in highway design. Automated design programs have had to be modified to take these factors into account. There has been extensive and increasing use of computer-simulation techniques and development of alternatives because of the growing and frequently vocal interest of citizens who formerly took highway locations for granted.

During the latter part of the 1960s, highway automation programs became increasingly oriented toward serving the needs of highway management and engineering, and record-keeping received less emphasis. Now that third-generation computing equipment is beginning to fulfill its promise, the scope of things that you can do with computers is limited largely by imagination and budget. The 1960s were pioneering years; the 1970s will be years of maturity and achievement in highway automation.

ACHIEVING ECONOMIC BENEFIT

Top highway department management must participate in the development of automation systems to ensure that the most economic benefit is derived from these large and expensive operations. Many judgments about automation matters that administrators do not like to make appear to be highly technical. In many cases, management is

required to establish a new policy and take the risks of disrupting an operation that is, to all appearances, stable and reliable.

There is no easy answer as to how top management can effectively direct the automation function. Yet the potential consequences of their failure to direct these activities are so important that the problem must be faced. Widely reported studies have shown that the majority of all computer installations in the United States are unsuccessful or barely adequate. The most prevalent reason for this failure is lack of top management involvement. Computer personnel, although their skills are highly technical, can be evaluated by top management. Their judgment, their ability to plan, and their ability to explain in detail existing and proposed systems in terms of costs, benefits, and alternatives can be evaluated by management.

Computer personnel can also be evaluated in terms of how effectively they manage their own resources. It frequently occurs that the department specifically charged with the responsibility for automation and better management techniques is the one most in need of putting those techniques into practice internally. We have found that to be the case in Washington; consequently we are revamping our computer organization. Wherever possible we are setting specific performance objectives and then using the computer to report compliance with those objectives, preferably on an exception basis. For example, we now provide our operations manager with a daily computer-produced chart, a histogram that shows at 5-min intervals which programs were executed, and how much memory and time they required. Each programming team leader receives a daily printout indicating which tests each of his crew ran, how long each one ran, and the kind of resources it used. We have exception reports that list all tests that required more than a minute of computer time, which in turn allow us to check productivity. All systems and programming projects are tracked against initial time and budget objectives, and exception reports are made of overruns and probable overruns. Production, work flow, and reliability statistics are produced as a by-product of our billing and cost-accounting functions.

The effect of the system is to give us objective measures both of how well we are doing today and, equally important, of whether our situation in relation to past periods is improving or worsening. One strong means of ensuring vital top management support lies in computer professionals' being able to demonstrate that they employ up-to-date techniques and judgment in managing their own resources.

We must face up to the cost-related problems of automation. When computers are used to do other than repetitive tasks, the work begins to get complicated and cost justification no longer is clear-cut. Management must then decide whether doing something with a computer that simply could not be done before is worth the extra cost—not only the computer time but also the time and effort to retrain people and change familiar habits. Management must answer such questions as: Can an expensive materials control system result in enough savings to justify the cost of programming, computer time, and reporting? Are the theoretical labor savings being realized? Unless management plays a direct and positive role, chances are that the labor saved by the new computer system will be frittered away on nonessential tasks, and overall costs will increase.

ORGANIZING FOR AUTOMATION

Most highway departments have skillfully applied computers to the high payoff parts of their organizations. This certainly indicates that automation activities are as amenable to sound management techniques as are the traditional areas. Whenever organization is discussed, the controversial matter of centralization versus decentralization arises.

Although the answer to centralization versus decentralization depends on the specific circumstances involved, it is becoming increasingly practical to have the best of both worlds. In Washington we are planning to place the power of the computer, through remote terminals of various kinds, along with access to its banks of data, information, and programs in the hands of the person who most needs it to do his job. This is decentralization of control and of computing power; yet the same computer and systems will be providing higher management the summary information taken from the basic field records.

BALANCING OF RESOURCES

There should be a good balance of automation resources among the major segments and functions of highway operations. Likewise, automation activities must strike a balance between the reduction in manual effort and the cost and effort required to make this reduction. Because the cost of automation increases as the square of the complexity, a basic aim of highway management must be to carefully allocate its automation budget. Therefore, the balancing of resources and allocation of automation budgets among competing users is a top management task that ought not to be overlooked or avoided.

Because automation is expensive and scarce, particularly in regard to highly skilled system designers and implementers, it is necessary for management to require that all data processing operations be economically justified and that the automation department's implementation priorities be the management's priorities, not vice versa.

LONG-RANGE PLANNING

Highway departments, much more so than most organizations, are accustomed to dealing with long-range planning. The need for careful long-range planning in automation development is fully as important as in any other departmental area. The effect of automation decisions made today will be felt several years from now.

Plans ought to consider the increasing level of coordination and information interchange that is taking place between agencies at all levels. Agencies with which highway and transportation agencies traditionally did little business now are creating systems and procedures to which we must respond. One example is the requirement for population statistics. So-called birth-to-death records are being created at the state level, and perhaps national records will result from this work. Highway management must respond and furnish these statistics to feed that system. Conversely, transportation agencies will be able to use the information derived in making better projections of transportation needs as they relate to total long-range planning.

The impact of the demands of others on our departments is measurable in terms of additional time and money. However, this type of requirement is going to be imposed on highway departments in the coming years, and we must be prepared to meet these demands and at the same time control the cost.

How we can best manage automation to meet the information needs of others is an important question. A first step is an understanding of information requirements among the various legislative contacts and formal or informal communication among executives of the various agencies. In state government, a central authority should be established for developing information requirements that affect other agencies. This has been done in Washington and several other states. In this way needs of statewide impact can be evaluated, judged, developed, and implemented in a relatively objective manner because decisions are based on statewide goals and objectives. Such an authority can and generally will result in top management of individual agencies becoming more involved in the agency program. The success of this kind of program is heavily dependent on a willing, cooperative attitude among all involved agencies.

COORDINATION AMONG AGENCIES

Automation is taking an increasingly large share of government resources, including highway funds. Obviously, coordination among transportation agencies using computers makes good sense. Highway agencies, including local government road authorities, have the most to gain by working together and by sharing automation facilities and knowledge.

Traditionally, close cooperation has been practiced in road building among the federal, state, and local units of government. Counties and cities have generally welcomed the exchange of ideas and techniques in the design and material-testing aspects of highway construction. Now it is time to extend this exchange of ideas and techniques to the automation area. We cannot overemphasize the importance of the existing exchange programs, which are key elements in the coordination of highway automation programs.

Expansion of such exchange programs is essential for the most effective expansion of the data processing system and the total automation program. Participation in the exchange programs by agencies and industry helps to ensure the use of progressive automation systems that are in the best interests of both government and industry.

SHARING OF FACILITIES

Small agencies cannot afford the investment in equipment and personnel required to perform many complex engineering and administrative functions. Many of these applications are available at state highway facilities. Increased use of state-managed automation facilities and systems will benefit local government. The direct cost to these units will be lessened because the state has already paid for the system developmental costs, while major operating expenses are allocated to the larger users. In Washington, we foresee a greatly expanded program of training, promoting, and assisting the small local users—particularly the engineering users—in the use of our computing facility. We see evidence of a strong need and a strong demand, and, at the same time, the additional drain on our resources is not too great.

CONCLUSION

Highway automation systems are so diverse in type and complexity that they defy ready classification; however, in general, the good systems meet the criteria of lower costs, faster results, greater accuracy, and facility for handling complex tasks. In many cases, especially for those programs dealing with administration and management activities, it is extremely difficult to apply these criteria to demonstrate conclusively the likely achievement of tangible monetary benefits. Consequently, management must understand the systems that are being developed and the elements that constitute those systems. Management must continue to relate its decisions regarding system development to the long-range goals and objectives of the agency. Management must also have the courage to make conclusive decisions based on information and judgment that cannot always be defined in strictly monetary terms.

WHY AUTOMATION SYSTEMS IN HIGHWAY DEPARTMENTS?

Wesley J. Burmeister, Wisconsin Department of Transportation

In reviewing Wisconsin's electronic data processing and management information systems, which are among the best, I found a consistent failure on the part of top management to manage data processing applications. If we are to be administrators, we must define management and engineering objectives so that system analysts can use the computer to help us achieve our objectives. To gain an understanding of the automated systems and to properly structure them within the highway department, we must provide frequent, tough-minded reviews of the operation. We must insist on quality-oriented performance and, above all, staff our divisions with outstanding business-oriented people to operate our automated applications.

I believe the following factors determine the course of automated systems: return on investment, managing by objective, and exceptional people. The highway department that fails to control costs, to set goals and use them to evaluate performance, and to employ outstanding people is headed for trouble when it automates its systems.

One of the most dangerous developments in our history has been the effort to produce automated systems that replace managerial or engineering judgments. Certainly processing of large amounts of rapidly changing data, the use of mathematical simulation formulas, and the development of rapid reporting techniques have served to provide the manager with a better set of data on which to base decisions. However, technocrats who propose to develop machinery to replace the judgment of the administrator are proposing trouble.

Why, then, automated systems in highway departments?

At first, the main function of highway departments was to "get the farmer out of the mud." From this, departments have evolved into organizations charged with the responsibility of providing safe, functional transportation networks compatible with the environment at a reasonable cost. This means that a myriad of information and alternatives must be considered by engineers and management to ensure that transportation facilities meet these objectives. To analyze this information, most departments are, or will be, utilizing computer-oriented processing for accident location and characteristics studies, area traffic projections, land use studies, network traverse adjustments, geometric calculations, earthwork design, topographic and perspective views of proposed facilities, and financial systems to provide direction and control. Highway departments must continue to utilize computers to automate such information systems in order to give the public a safe, functional transportation facility at a reasonable cost.

One of the significant aspects in the operation of state highway departments during the 1960s has been the initial attempt to solve numerous and complex problems with the systems approach. The mere fact that we now use and recognize the term systems approach represents a significant shift in our approach to problem-solving and decision-making. Probably for the first time we are looking at broad problems and determining requirements and designing solutions without regard to traditional constraints such as jurisdictional boundaries, organizational structures, and local political pressures.

This trend toward solutions in terms of systems applies to all the problem areas that beset the highway environment: urban renewal safety, pollution of natural resources, transportation, and land use. These systems have required automation through use of the computer.

The world of automation has been characterized by data processing thresholds. In the earliest days of punched cards, the first major threshold was the ability to print as well as to tabulate. Recent thresholds that are opening up new applications are those of mass storage and remote terminals. In particular, problems of urban and rural highway management are becoming much more accessible to data processing through the use of mass storage and remote terminals.

The most serious problem area within the highway department is the need for emphasis on planning. Before the advent of the systems approach, government agencies did not consider the effects of their projects on other units of government or on society in general. They usually implemented their projects without any formal planning; in many cases the only plan that existed was the engineer's drawing and specification.

The key to the development of a plan is, of course, information or data. The collection, organization, and analysis of valid data are the basis for decisions concerning plan development and refinement and expenditure of funds. The range of highway data that can be collected is potentially limitless. Consider the multiplicity of situations, environments, and conditions we all have experienced while driving a vehicle. It takes relatively little imagination to speculate on a broad range of detailed and general questions concerning the basic categories of highway data—accidents, traffic, physical characteristics of the road, design characteristics, land use, and soil condition.

One of the principal problems in organizing highway data is the numerous categories of data in which planners are interested. Each data category has a large number of separate data elements. However, it is not the amount of data alone that presents difficulties; the problem is complex because we must be able to use three types of data—point, length, and area data—individually and collectively. Without the capability to cross-reference data we would not be able to ask a series of sequential questions that are essential to making a value judgment.

There are several major reasons why an automated system for maintaining highway data is needed. One of the principal limitations of manual systems is their inability to respond rapidly and accurately to a wide variety of unstructured user requests; i. e., the manual system does not lend itself to a flexible response, but rather all outputs are strictly formulated and produced by special problems. Therefore, if a change in the output is desired, or a totally new output is requested, considerable time and expense are required to respond to the new request.

A second deficiency of manual systems is their inability to process and type retrievals that determine where conditions overlap. A condition or information on one highway project may affect two or more other projects. This ability to determine overlap conditions for two or more problems is an absolute requirement for decision-making.

A third deficiency of the current systems, which ties directly to the first two points, is the manner in which the data variables are organized and stored. Our methods of computer file creation and maintenance must be modernized and improved.

There are also new data processing capabilities and technologies that are attractive to management. Foremost of these new capabilities is graphic plotting. Why must we read a printed report when a graph would be better? This capability not only would support a plot or mapping requirement but also would be especially useful in showing alternative designs and their relationships to one another and to existing roadway networks. The advantages of being able to show meaningful geographic relationships graphically during the planning and design stages is extremely effective, especially when one considers that the users are almost exclusively engineers.

A second new technology to be utilized is remote-inquiry terminals. Wisconsin is organized into nine separate highway districts with their respective operations scattered throughout the state. Most information requests are unstructured one-time requests that originate at the district offices. The use of remote terminals should increase availability of information. Even if quick response time is not an absolute requirement, accessibility and convenience of the information will provide engineer-computer interaction and improve the alternative problem-solving analysis. Improved highway designs can be achieved by providing direct engineer-computer interaction.

In addition to its engineering applications, advanced data processing can improve statewide data files. The use of remote terminals to satisfy queries, make corrections

to the files, and provide transaction confirmation will also assist users in the outlying districts by providing a direct communication line with the data files located in the central office. In addition to the districts, the various functional groups (design, planning, maintenance, and traffic) located at central headquarters will utilize terminals to process their queries.

I do not know of any computer installation that is cheaper to operate than a "human" one. We should not expect to reduce costs by using computers; however, we should expect and demand quantitative data that are timely and useful. We should expect to reach "the ultimate" in terms of the best design—which is a "savings." We should expect and demand that the highway designer do more creative design work with the automated system and leave the labor of hand calculations to the computer. We should expect to automate applications previously considered impracticable because of the need for extensive hand calculations.

Each automated system should be designed as an integrated subsystem within the framework of the larger overall integrated operations system. Wisconsin has conceived and is implementing such an overall system as a long-range objective. The Wisconsin integrated operations system (IOS) consists conceptually of a number of management and computer-based subsystems that will ultimately form a total system of procedures and information processing for the operations of the department.

The project development system, as a management or procedural system, includes functions of highway planning and design that will both require and produce technical and financial information. The highway engineer system constitutes the technical engineering information component of IOS and, as a computer-based design tool, will act largely as a generator of data during the actual physical design phases of highway improvement projects. The program budget system and financial operating system are the procedural and computer-based components of IOS directed toward the budgeting, resources, and financial information aspects of the department's operations. The highway network data and information system is to act as the central repository of technical information and provide for the storage, processing, and output presentation of such information in support of the planning function and accomplishment of improvement projects. This system must also support the routine federal reporting requirements imposed on the divisions.

The functional areas that the IOS is designed to support include the full spectrum of planning, design, land acquisition, construction, operation, and maintenance. Although the system conceptually can provide support in all these areas, it has been designed as a series of modular packages intended for continuing evolutionary implementation over a long period of time. The concept of evolutionary development and implementation advocated by the Wisconsin Division of Highways for IOS is the most desirable approach to such an automated system.

WHY DO WE NEED COORDINATION OF AUTOMATION SYSTEMS?

Ralph D. Johnson, Roy Jorgensen Associates, Inc.

I seriously question both the need and the advisability of trying to achieve coordination of automation systems all the time. A review of one example demonstrates how too much attention to coordination can lead to voluminous computer printouts that are worthless.

In the 1940s, the maintenance control section concept was developed to serve as a common reference base for all highway location data in a number of planning and management areas. Control sections were initially used to evaluate the adequacy of the road system in relation to existing and projected traffic burdens. The sections were defined to provide segments of the road system within which the existing road character and the traffic served were reasonably uniform. The control sections accomplished this; however, for more sophisticated economic evaluations, it was concluded that road section maintenance costs should be established and that the incidence of accidents should be related to the road sections. Consequently, many highway departments established maintenance cost reporting systems that related all maintenance expenditures to control sections, and many departments grouped accidents by the control section in which they occurred. Because these analyses were computerized, it appeared that maintenance data handling could be expedited and a valuable coordination of output provided.

For years, the use of control sections provided the basis for effective analysis of priority needs in the development of highway programs in several states through a procedure called sufficiency ratings. From time to time, they also provided the basis for the objective development of total highway needs estimates by procedures largely developed by the Automotive Safety Foundation and pursued strongly by the Bureau of Public Roads.

It was in the maintenance cost area that control sections were used most extensively. Most departments that established maintenance cost reporting systems continued the daily recording of maintenance work by control sections and maintained cost summaries. For highway safety analysis in planning, accidents were recorded by control sections and much experimentation was undertaken to try to relate accidents and highway features by use of this device.

The use of control sections, therefore, seemed to have a great future as a sound basis for coordinating inputs into several analyses; however, this future never materialized. Although control sections were useful in needs analyses, their use in maintenance cost analyses proved to be almost a dead loss. There was almost no worthwhile use of the voluminous computer output from maintenance reporting systems in many states. The maintenance data were found to be too unreliable for coordination with other needs study data. Furthermore, it was found that sampling data or generalized maintenance estimates served the needs purpose adequately. Some highway departments made summary reports of the data and distributed these presumably so that maintenance managers would examine their costs in relation to other managers' costs and use the unit-cost data for budgeting. However, the lack of validity of the data was too easily recognized for the summaries to be useful for either purpose.

The traffic safety area is another area where control section reporting proved meaningless. This was not immediately apparent in that some safety improvement programs were being structured on the basis of where the most accidents were occurring—except that it was difficult to count the spots on the accident spot maps. As researchers further analyzed traffic accidents, however, they found that the location of accidents by

control section was not sufficiently refined to provide the values needed for pertinent identification and cost-effective correction of high-accident locations.

As a coordinating device, therefore, control sections that once seemed to provide a sound basis for coordinating all highway location data for various analytical purposes have proved to be of little value. Even in the needs study area, control sections, although they proved to be a valuable basis for reporting and analyzing location data and are still used in some places, are now a completely dispensable tool.

What can we learn from this history of control sections that is pertinent to our discussion of coordination in automation systems? I believe we can learn at least three lessons, and, from these lessons, we can establish three principles that should guide us in any coordination of systems we undertake in the future—automated or otherwise.

The first lesson is that coordination of systems may not always be a worthwhile objective. Control systems proved valuable in the area of needs measurement even though they failed to work out for the other two purposes that they initially were conceived to serve.

The second lesson is that we should review periodically where we are going with our systems. We are in business to accomplish things; a complex system that produces useless maintenance cost output for 20 or 25 years may not be the only mistake that highway departments have made in coordinating data systems of a similar nature.

The third lesson is similar to the second but may not be reflected as such in the control section experience. It is that systems—automated or otherwise—should be designed backward from decision input needed to achieve well-defined basic objectives of the organization. Reviews of systems, continually made in the regular management process and occasionally made in depth, should concentrate initially on how well the system provides decision input data. Further, the objective toward which design of a system of any kind is directed should never be systemization itself. Systemization should be viewed only as a means to an end; the end should be the achievement of the organization's basic objectives more efficiently or more cost effectively. If we had learned this better in connection with control sections, we would have reviewed maintenance reporting systems in terms of obtaining worthwhile maintenance cost and accident data that could help in decision-making.

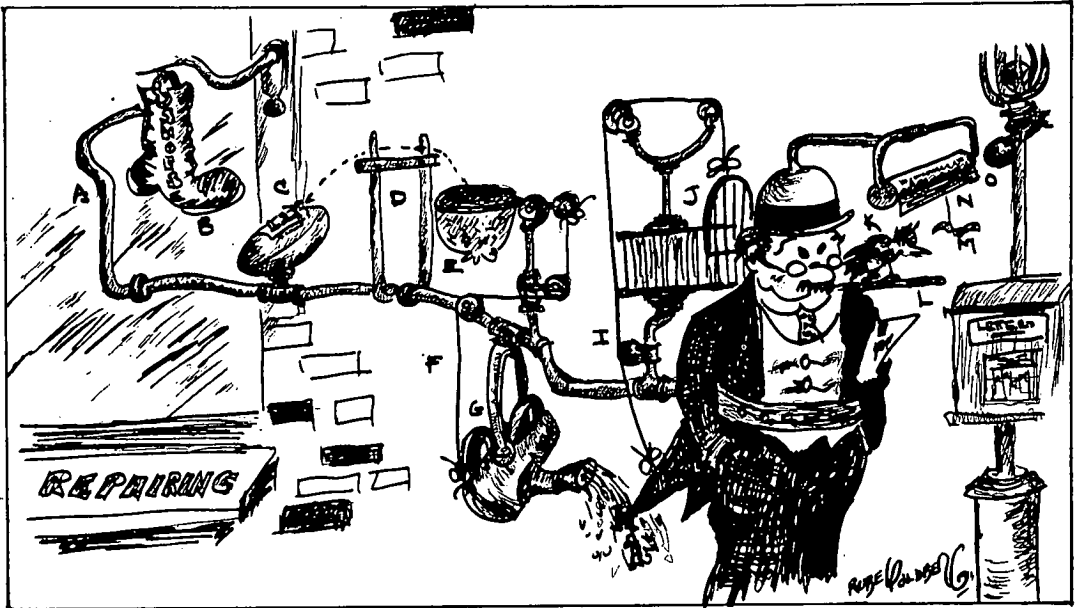
The principles that we can relate to these lessons are as follows:

1. The design and subsequent review of any system or combination of systems should begin with defined decision input needed to achieve basic objectives.
2. There should be continual management review and occasional in-depth study of all systems to see how their output relates to the provision of needed decision input.
3. Efficiency and cost-effectiveness in providing needed decision input should be the sole criterion of whether, and how much, systems should be coordinated.

In connection with the first of these principles, a great cartoonist, Rube Goldberg, amused us for a number of years by designing complex systems for accomplishing insignificant things (Fig. 1). Is a complex computer system that produces worthless output any less humorous than Professor Butts' system? From the standpoint of a noninvolved observer, it may be. From the standpoint of a stockholder or taxpayer, I doubt that it would be. Regardless, there is a very real danger of producing this kind of automation system if we fail to observe the first principle: to design systems exclusively to provide needed decision input for the achievement of basic objectives.

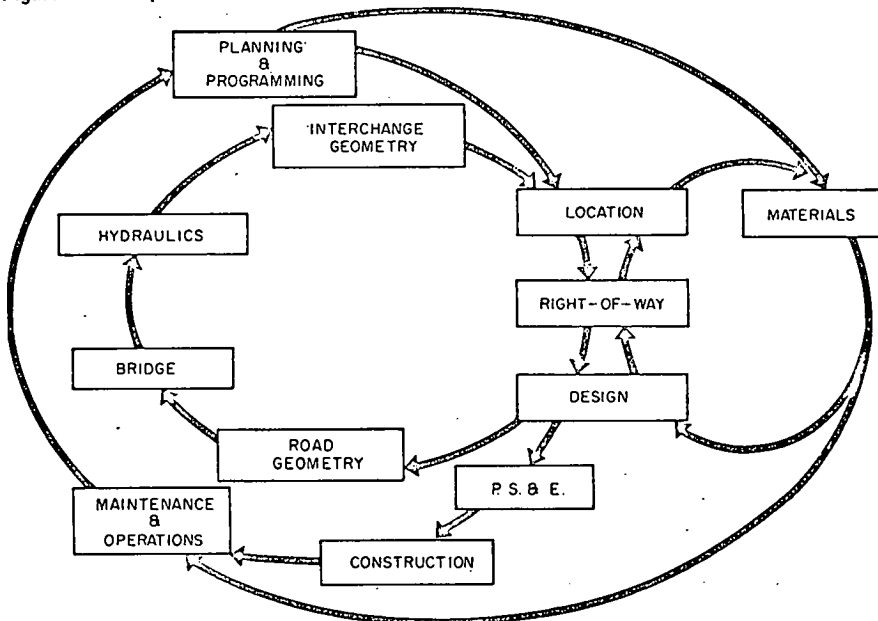
How does this relate specifically to the coordination of automation systems? It means that coordination of automation systems should be designed backward from decision input. This would rule out, for example, the concept that a central data bank can be structured to contain provisions for all data conceivably needed for most analytical functions in a highway department and to adequately provide a system of linkages to deliver needed data to any user on demand. This concept would be ruled out because, designing backward from decision inputs, we would first design the systems providing the basis for the decisions before we identified the data input required for these systems. Even with current systems, we need to go this route because all of our current systems may not be right. Furthermore, as is commonly known, it is an unprofitable task to obtain summary data that are outside of the data linkage design from a data bank of this kind.

Figure 1. Professor Butts mails a letter.



PROFESSOR BUTTS GETS CAUGHT IN A REVOLVING DOOR AND BECOMES DIZZY ENOUGH TO DOPE OUT AN IDEA TO KEEP YOU FROM FORGETTING TO MAIL YOUR WIFE'S LETTER. AS YOU WALK PAST COBBLER SHOP, HOOK (A) STRIKES SUSPENDED BOOT (B) CAUSING IT TO KICK FOOTBALL (C) THROUGH GOAL POSTS (D). FOOTBALL DROPS INTO BASKET (E) AND STRING (F) TILTS SPRINKLING CAN (G) CAUSING WATER TO SOAK COAT TAILS (H). AS COAT SHRINKS CORD (I) OPENS DOOR (J) OF CAGE ALLOWING BIRD (K) TO WALK OUT ON PERCH (L) AND GRAB WORM (M) WHICH IS ATTACHED TO STRING (N). THIS PULLS DOWN WINDOW SHADE (O) ON WHICH IS WRITTEN, "YOU SAP, MAIL THAT LETTER." A SIMPLER WAY TO AVOID ALL THIS TROUBLE IS TO MARRY A WIFE WHO CAN'T WRITE.

Figure 2. Example of TIES.



If, on the other hand, analytical systems are designed to provide specific input needed for decisions and are found to utilize the same basic data, then it is obviously sound to specifically develop a data bank structure that will efficiently provide the source data for these systems and, perhaps, to these systems through automation processes. There would be no limit to the number of systems a data bank could serve on this basis. However, a data bank structured in this way would need to be quickly adaptable so that new data arrays could be provided when the analytical system is changed because of new or improved technologies.

It is unrealistic to expect that an automation system can be designed practically to carry through the analytic processes from planning to construction or planning to maintenance on the computer with input from engineers being made at different points along the way. Figure 2 (1) is not very meaningful in indicating procedural or data interchange relationships among the various highway department functions shown. In fact, many times there is no continuous procedural flow. Planning, for example, employs a completely different type of procedure than that utilized in location, and the procedures in right-of-way acquisition are another set. True, there is a point in time when planning procedures result in identification of a project and, at that point, there is an interface between planning and location. True, location of a project provides a basis for right-of-way acquisition, and right-of-way factors are important in location. True, there are many common data needs. However, needs for various data far exceed needs for the same data. The analytical processes are completely different for each function, and the type of decision-making and even the decision-makers are different. Any system that tries to provide for some of these things simultaneously (and several should be conducted simultaneously) and for others sequentially (and several should be conducted sequentially) would be very complex indeed. Fortunately, the figure does not include financial management and scheduling and control areas, which apparently are expected to coordinate differently or perhaps not at all.

More recent diagrams of systems similar to the Total Integrated Engineering System (TIES) have shown pie-like divisions that represent major "engineering" functions and contain more detailed functional breakdowns, with a data bank core at the center. These diagrams are no more descriptive of the actual relationships involved than the one we have chosen for illustration. The data bank idea does not contribute much to a conceptual definition because we have already discussed the impracticality of data being provided to all systems from an unstructured data bank. In a structured data bank, data content and form of entry are arranged specifically to provide efficient data input into one or more analytical systems which, in themselves, are designed specifically to provide the necessary information for a management decision.

To determine how best to provide the information needed to arrive at a management decision, one must decide whether a computerized routine for a particular analysis should be provided. The objective should not be to get everything on the computer. In some cases, computerization or automation of an analytical process will not be cost-effective. Generalized examples are (a) when application frequency is low, (b) when the analytical processes are not stable, i.e., new developments occur and change computer program requirements frequently enough to destroy the aggregate advantage of computerization, and (c) when the results of the program cannot be specifically detailed in advance in terms of the information needed for management decisions. It is certainly desirable to have research projects on computer systems, but there should be no doubt, in advance, that the projects do constitute research that may have successful, partially successful, or unsuccessful outcomes.

At least two basically different kinds of management systems that present different demands on and opportunities for automation must be recognized in structuring practical automation systems in highway departments. First, there is the preconstruction project production line; second, there is the management support system group consisting of such functions as planning, budgeting, programming, scheduling, personnel management, financing, controlling, and, possibly, maintenance.

The production-line group, consisting of location, materials analysis, design, and right-of-way acquisition, appears to present the largest potential for full-scale automation. Functions in the group have these characteristics in common: (a) Within the

limits of periodic change, the analyses are largely routine; (b) computerized applications already are available for many of the analyses; (c) the functions interface sequentially, with data and decision output from one providing data and decision input to another; and (d) most use common source to some extent. They also represent functions that are susceptible to a single programming, scheduling, and control system, which also can be computerized or automated.

These functions provide the real target for TIES and other integrated engineering systems. Several so-called subsystems have been developed (or largely developed) for TIES such as a hydraulic design subsystem, a road design subsystem, and a bridge engineering subsystem. In addition, several state highway departments and other agencies working apart from TIES have developed in conjunction with their own integrated system concepts full or partial systems for road design, bridge design, hydraulic design, location, and right-of-way acquisition. Generally these systems have been developed function by function, and in the area of common data utilization or machine interfacing little has been accomplished. There has been considerable progress, however, in the development of a production-line system. The use of common data utilization or machine interfacing is worthwhile only when it results in a cost-effective benefit such as speeding the preconstruction phase, reducing the number of personnel, or providing a better design product.

The same principle applies to what we have called the management group of systems. For the most part, these systems do not represent sequential steps in a basically single-target process. In general, they have little in common with the production-line system and with each other.

Planning systems are directed toward providing bases for the production line, but the direct inputs, for the most part, are identified projects. This is not altogether true because a clear distinction is not made between processes that are called planning and those that are called location or design. Also, processes such as location and design utilize some planning data. Where there is this utilization, there obviously ought to be coordination of systems, whether they be computerized or not, to arrange for transfer of data with maximum efficiency.

The production programming, scheduling, and control system—sometimes considered as a planning function—is a candidate for extensive automation. However, there is no obvious reason for coordinating this system with the systems in the production line; they do not use the same data at all. There is reason for some coordination of this system with the budgeting system and the personnel management system; however, it is not at all certain that data transfer through machine processes would be advantageous in any way.

There are other developed or partially developed automation systems as well as potentials for new automation systems in planning. Simulation and other analytical models are available for such things as traffic systems analyses, continuous highway needs analyses, environment planning analyses, and certain economic analyses. There is some interfacing and desirable interchange of analytical procedures among these models, and there is considerable sharing of common data. It would be profitless, however, to try to arrange for transfers of data or common machine processing without being highly selective in the determination of where these interfaces should occur.

Selective coordination may also be desirable between maintenance and planning systems, maintenance and other production-line systems, and maintenance and budgeting systems. Automation systems for maintenance management are largely self-contained, however, and need no extensive interface with other automation systems. There are uses for some road inventory data gathered for general purposes, and maintenance uses should be taken into consideration in gathering and filing these data. However, in general, it looks as if maintenance should largely rely on independent systems.

The principle of selective coordination applies not only to automation systems and potential systems for the functions mentioned but also to systems and potential systems in financial and personnel management, communications, and other highway department operations. It applies equally to systems applicable to a larger field of transportation such as departments of transportation. The principle of backward design (from management decision input) also applies to all automation systems or combination of automation systems regardless of where they may be used.

If we follow these principles, we will be better able to avoid the following examples of bad automation systems:

1. An automated system of work-reporting or cost-accounting that produces summary output for which there is no practical use;
2. An automated system that produces diagrams of highway features that are only used, when they are used, because the users are ignorant of other sources that are available at much less cost;
3. A computerized bridge design system that is used for only one or two design applications;
4. A scheduling system that is not effective either in scheduling or in controlling production;
5. A complex, comprehensive data retrieval system that is of little practical use in any of the processes of highway planning, engineering, or management because data retrieval is based on complex linkages that must be established in advance and therefore are rigidly inflexible;
6. Any kind of a system that produces voluminous data, such as equipment usage and maintenance reports, that are never actually used;
7. Systems that never seem to be completely developed as the developmental expenditures mount up; and
8. System conversions that do not function as well as the old system.

That both principles are also applicable in general business and industry should be evident from an article that appeared recently (2). In general, the article documented instances in industry where computerized systems, during the last decade, have failed to live up to the expectations of the purchasers. Most of these instances involved automation systems used in large companies in Britain and the United States. According to the article, the systems were (a) too expensive to install, operate, and repair and (b) ineffective in producing satisfactory results.

After analyzing the underlying problems, largely through conversations with executives both in the affected companies and in the computer industry generally, the authors of the article made the following conclusions:

1. The current capability of computer systems has been oversold by the industry—particularly the hardware companies;
2. Lack of standardization, adequate training, and control and shortages of trained personnel have created large technical deficiencies in the computer programming area;
3. Managers have inadequate understanding of the use and capabilities of computers and computer systems;
4. Low-level personnel, such as the head of a data processing division, are left to make basic decisions about computer installations and systems; and
5. Those associated with computers and computer systems are often more interested in and aware of the complex electronic functions of the machines than they are of company objectives.

Some of these conclusions may be superficial or even misleading. For example, what managers may need to know about computers and computer systems is (a) that electronic computers are only machines that combine the attributes of an extremely fast desk calculator and a filing case; (b) that they can only process data to obtain answers to calculations or chains of calculations built into them and retain or provide the raw data and answers in initial or summary form; and (c) that computers are not even very efficient in performing calculations, just very fast.

The idea of man-machine systems, where the electronic computer performs all of the routine calculations of dozens of people while a professional sits back conceptualizing and feeding in decisions at key points, is largely a pipe dream.

Executives would be better managers if, instead of trying to understand computers, they would take a close look at any proposition to automate existing or new procedures and answer the following questions: Is the system designed to supply specific needed output for management decisions? Is there any likelihood that it might not achieve this specific result? What problems are likely to be associated with it? Does it have cost-effective advantages over current systems?

The more obvious aspects of coordinating automation systems apply only when it is rationally decided that coordination is needed on the basis of the principles we have stressed. For example, where better efficiency and cost-effectiveness may be served by machine transfers of data from one system to another, it is obvious that attention should be given to compatible formats of one subsystem's output and another subsystem's input. If summary final values are the only data to be transferred, then coordination with respect to these values is all that needs to be considered. If there are to be transfers of basic data content or sharing of basic processes, considerations need to be extended to more complete compatibility of data formats and compatibility of program language.

Other obvious considerations in coordinating automation processes may relate to potential variances in basic computer needs and applications such as between different highway department processes. It is quite possible that maximum automation and computer use in some processes may not demand the machine capacity that minimum automation and usage may demand in others. Obviously, coordination is needed to ensure rental or purchase of a computer with optimum capacity. Types of computer applications vary among processes. Computer applications for maintenance are quite different from those for bridge design. Specific computer systems have been designed for different types of applications, including different hardware. Once more, coordination obviously is needed to ensure rental or purchase of adequate hardware.

There is no basic reason why computer programs need to be written in the same computer language when they apply to unrelated applications. When it is anticipated that the output of one program will be used as the input for another, efficiency may be increased by using the same language for both programs. Use of a common data bank is facilitated by using one language. The additional training necessary to equip programmers to write in more than one language is also worthy of consideration. Of course, the days of computer language problems may be numbered as we approach the development of a universal computer language.

Figure 3 shows a planning system that can be automated to excellent advantage. Perhaps the most extensive potential for automation is in the plan cost analysis and program through work plan and implementation steps shown in Figure 3. Plan cost analysis differs from the conventional needs study by providing for continuous evaluations of the entire highway plan and potential or actual modifications of the plan. It is used continually in the planning process to evaluate changes in concepts of such things as specific routings, design standards, and levels of traffic service.

The program through work plan and implementation procedure has already been discussed to some extent; it combines programming and the scheduling and control processes. In this case, the procedures can be carried out effectively through a sequential coordination of subsystems.

Figure 4 shows how an automation system for processing maintenance work records can be directed toward management decisions needed for the effective scheduling and control of maintenance operations.

Figure 5 shows a central core data system as related to analytical systems in a multiagency traffic safety program. It shows one basic group of data that can be used to serve many purposes. The data are structured in such a way as to be readily available for several subsystem analyses, largely automated. The subsystems are designed to provide needed management decision input. Because the subsystem analyses require more data than those included in accident reports, nonreport data are also made part of the central core record and are conveniently arranged such that all subsystems can have immediate access to them in the required format. How the data are arranged in the central file is not particularly important so long as they can be supplied immediately on demand. There are no useless data in this file.

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Figure 3. Recommended planning system.

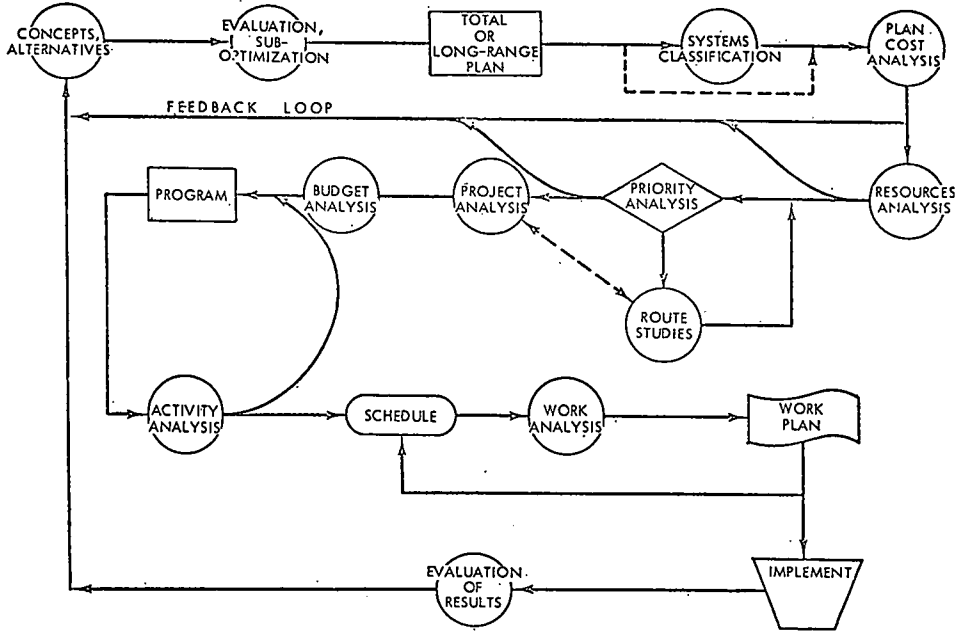


Figure 4. Recommended maintenance management system flow.

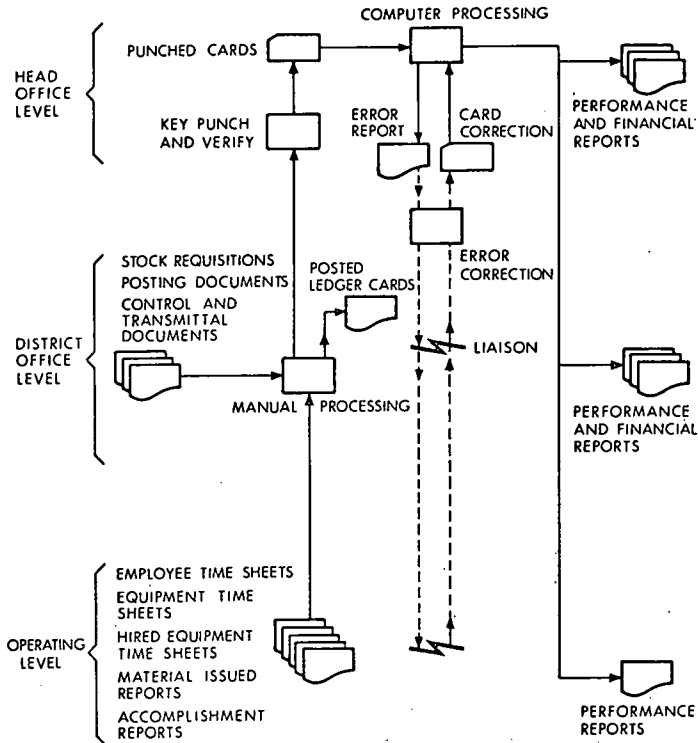
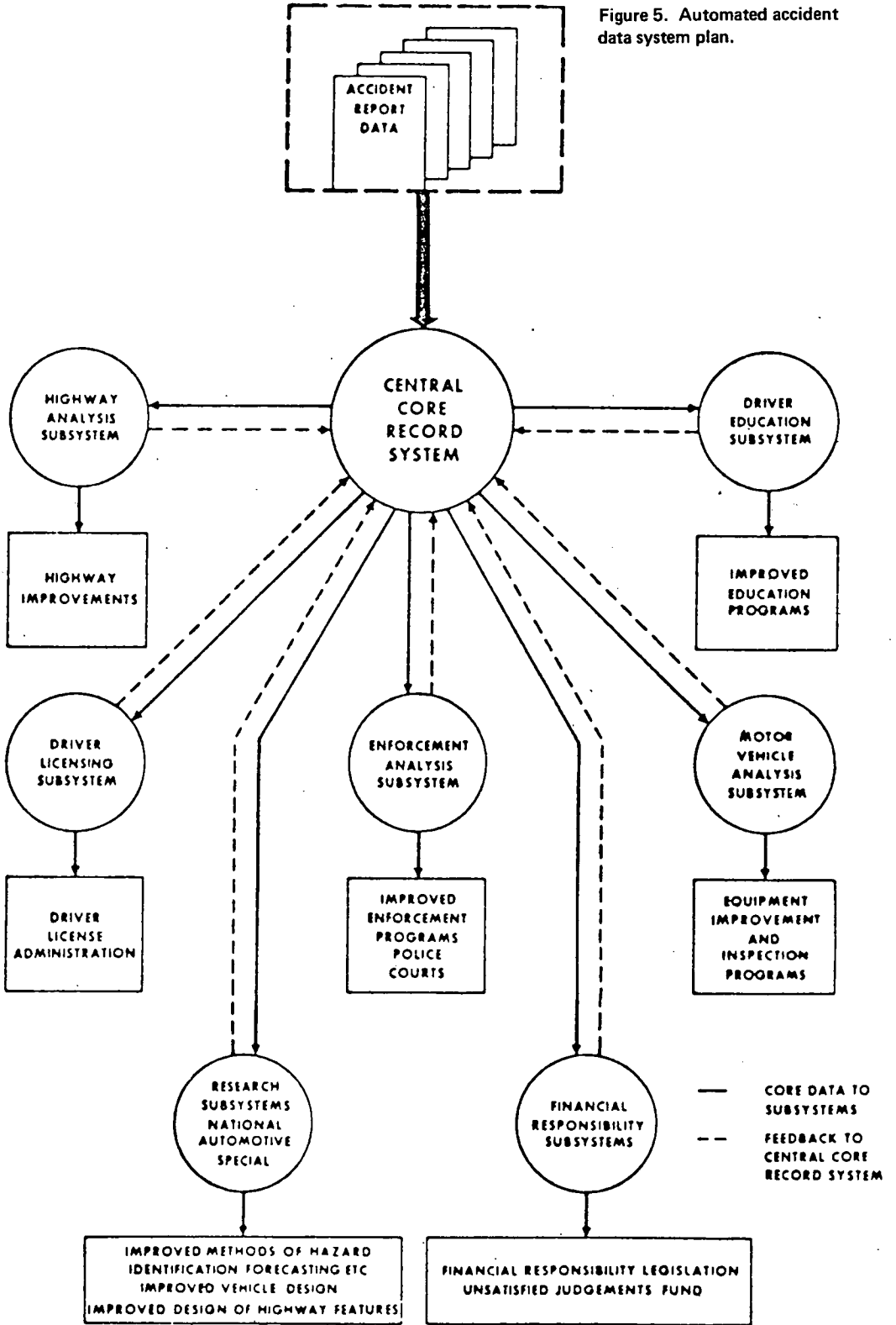


Figure 5. Automated accident data system plan.



COMPUTER APPLICATIONS MUST BE MANAGED

Marvin E. Hermanson, Minnesota Department of Highways

Very few highway department managers have received any formal or detailed computer education during their academic or working years. Because of their ignorance of the computer field, many managers do not make computer-related decisions; they relinquish this responsibility to computer personnel who frequently make poor decisions. Management must make computer-related decisions if the maximum benefit is to be derived from automation.

The following conditions are typical of a highway manager's department.

1. It is a technical and engineering-oriented agency that historically has been dependent on a separate (usually in-house) organizational unit of computer professionals;
2. Over the years an ever-widening communications gap has developed between top management and assistant top management;
3. The advice and guidance received by assistant top management have often been tailored to meet the needs of automation personnel and hardware resulting in the delay of important (but not easily automated) systems; or
4. There has been a lack of adequate departmental statements of goals and objectives and plans to fit individual systems into an objective-oriented partial total system; and
5. If the data processing capability has been merged into a larger centralized effort, or turned over to an outsider, the department is a captive customer, foregoes much of its former flexibility, accepts the higher costs, and follows rather than directs priorities concerning processing and professional services.

What can top management do about these problems? For one thing, top management must apportion time and resources for some "self-education." It has to be able to evaluate alternative courses of action and to assess their impacts. It must be able to influence potential managing systems by defining their scope, the interrelationships between individual efforts, and the specific results desired. There also must be agreement among management on departmental goals and objectives as they pertain to computer application. Management must be certain that each new effort will be toward a partial total system rather than another "stand-alone" independent system. Follow-up in the implementation and results stages is vital if management is to really control computer applications.

All of the foregoing steps must be taken by management now because future computer applications will be more complex than present ones.

The following are computer-related trends that a typical chief administrator might expect to occur during the decade ahead:

1. "Knowledge explosion" in which the sum total of human knowledge doubles every 5 years;
2. National data center, with attendant debates over security and invasions of privacy;
3. Large-scale time-shared computers with rapid development and use of more advanced terminal hardware (on-line usages);
4. More computer-to-computer direct communication;
5. The beginning of on-line banking (the checkless society);
6. Easier programming due largely to expansion of man-machine interaction through education and language simplifications;

7. Recognition that traditionally independent systems (both automated and manual) must be judged and handled as parts of whole systems;
8. Expanded use of the technique of automated simulation for decision-making;
9. Strong need for expanded computer educational efforts at several levels; and
10. Growing emphasis on payback evaluations through use of cost-benefit techniques with considerably less return on investment from the new data-base type of applications.

Most highway transportation agencies have always maintained a progressive attitude toward utilizing automation in their operations. However, developments of recent years have created the need for a second look at the whole agency operation in relation to current and future needs. The following are a few key checkpoints that could become the basis for a model statement of policy:

1. Develop and maintain adequate departmental goal and objective statements to be used as guidance and direction for evaluating and implementing all systems efforts;
2. Ensure that multiple-user inputs offer alternatives, minimize risk, and foster participative decision-making and internal cooperation;
3. Inventory and analyze all manual and automated computational data-information systems and annotate their contributions to management objectives;
4. Develop all management and information systems to be potential parts of an over-all system and to be compatible with any external change or system as required;
5. Ensure that executive or administrative decisions can override economic analyses reports and cost-benefit ratios;
6. Maintain a business-like operation wherein quality service is provided at acceptable costs;
7. Provide sufficient time and funding for the development of a necessary level of computer and systems knowledge (education) in both managing and operating ranks;
8. Establish a top-level review board to receive new proposals, monitor system applications in progress, audit cost-benefit appraisals, and make priority recommendations; and
9. Give adequate management support to the review board.

For every system or subsystem proposed or in the process of being designed for computer processing, management should establish and use a checklist to assure itself that the new procedure has potential benefit. If the proposal passes this review, it should then be given full support of top management.

For an initial proposal, the review board should apply the following six-step evaluation before a more detailed feasibility study is undertaken.

1. Is there a need for manipulation of data beyond the capability of either manual or key-driven equipment?
2. Is there a need for an increase in the degree of control over groups of items or dollars?
3. Is there a need for a reduction in the number of semi-skilled workers?
4. Is there a need for additional speed?
5. Is there a need for reports containing management control information that would be unavailable or impossible to get except by computer?
6. Is there a need for the large dollar reductions that the proposal offers?

If favorable answers to some of these questions clearly seem to support the prime goals of the department, then the proposal would appear to satisfy a need.

The next step would be to request a feasibility report in greater detail than was contained in the initial proposal that management evaluated. This report is reviewed by management, who decides the merits of the proposal. The feasibility report should clearly state the following:

1. Concept of the proposal;
2. Objectives to be achieved;
3. Areas in the agency that may be affected;
4. Plan of implementation;

5. Analysis of the plan's compatibility with other separate or combined efforts (to make up a partial total system);
6. Time table for accomplishment;
7. Personnel needed to carry out the project;
8. Amount of expected return on investment;
9. Method for incorporating the return, or reductions, into the operating unit's budget;
10. Total cost; and
11. Whether the plan's development will require discontinuing existing projects or programs.

In addition to the formal feasibility report there are certain supportive criteria that management also must consider by seeking answers to questions such as:

1. Will the stored data be reasonably accurate and current?
2. Once stored, will the data be maintained by someone who will feel a responsibility to keep them valid?
3. Will other departmental (or external) units use the data with confidence in their reliability?
4. Are the data likely to be neglected and thus mistrusted?
5. Will the data be compatible with new and modern accounting systems?
6. If the plan significantly exceeds the cost estimate, are you willing to make a positive decision to correct the overrun?

If a sufficient number of these criteria pass the management screening process, there still is one more important role for management before it initiates a project. It must directly share in the formulation of the project's objective statement and approve the form that its output or end results will take.

PART II

HIGHWAY DESIGN SYSTEMS

ENGINEERING SYSTEMS: AN OVERVIEW

W. A. Wilson, Jr., North Carolina State Highway Commission

The use of automated systems in engineering has eliminated much of the tedious work that has been necessary in the design and construction of transportation systems. High-speed computing systems enable the highway designer to consider many new options that were formerly beyond his reach because of time limitations. Automated systems are in almost constant use during roadway construction; they are used for transportation needs analysis and corridor selection and in the building process itself.

I will discuss as many automated systems as is possible, touching briefly on systems that are currently in use and looking ahead to systems that may be available in the near future.

The original concept of the TIES project was to integrate all of the major functions involved in building a highway. These functions are planning, location, right-of-way, design, construction, and maintenance. The major effort expended to date has been concentrated on the design subsystem, which is composed of roadway, bridge, hydraulics, and interchange design.

The Texas Highway Department is currently developing the roadway design subsystem for the TIES project. All of the program modules for this subsystem have been written and are in various stages of testing, evaluation, and documentation. The subsystem will be composed of the following design processes: electrotape data reduction; theodolite data reduction; geodetic traverse adjustment; side-shot calculation; intermediate point calculation; analytical aerotriangulation; strip adjustment; terrain edit and store; earthwork design; profile and cross section plot; design data edit and store; command-structured geometry; volumes/haul calculations; and perspective plot. Additional plotting capabilities will include modules for the following: general geometry plot; areas plot; alignment plot; and geodetic traverse plot.

Self-motivational training material related to the roadway design subsystem is in preparation. All course material developed will be field-tested in several states to ensure its effectiveness as a training aid. Its form will be such that it can be readily reproduced as needed for training purposes.

Most states are now using photogrammetric processes to obtain data about corridors that have been selected for design. The speed with which the data can be collected and put into a useful format makes possible the investigation of a corridor in much more detail. This comprehensive study of the factors that may have a bearing on the ultimate design of the roadway should result in the best possible design.

After a corridor has been selected, a corridor line is established and run in the field. Electronic data collecting equipment is used so that information about the line may be obtained as quickly and as accurately as possible. The use of such sophisticated equipment as Geodimeters for relatively short lines and tellurometers for lines of greater length have eliminated the need for tedious transit and tape surveys. Readings from these instruments along with information on atmospheric conditions, such as wet and dry bulb temperature and barometric pressure, are fed into a computer, which computes the actual length of line and its bearing. While this line is being run in the field, control panels are set at frequent intervals along the line to provide vertical and horizontal control.

When the corridor line and control panels are set, a time to fly this line must be established. To obtain photographs that show as much detail as possible, it is

necessary for the rays of the sun to be approximately parallel to the corridor line and at the same time to be at a vertical angle to the earth of greater than 30 deg. The azimuth of the line and dates on which the line may be flown are submitted to the computer section, and the exact times that those conditions will be met are returned.

After the photographs are obtained, a detailed contour map is prepared on a stereo compiler. This map is turned over to the preliminary designers, who study a variety of lines to achieve a design that meets all the necessary criteria. By using an earthwork system in conjunction with horizontal and vertical alignment systems, the preliminary designer is able to arrive at valid quantity estimates for the various lines that he is investigating. Once a preliminary design has been selected, the design line is tied to the corridor line and can be placed on the original photogrammetric manuscripts. The preparation of plan sheets and cross sections can then begin.

While the photogrammetric department or drafting personnel prepare sheets, geological and hydrographic final investigations are made by using the preliminary data. One automated process that has reduced geological investigation time is the use of seismological methods of subsurface investigation, which replaces rock boring. In this system, a sound generator is used in conjunction with a seismograph to determine the speed with which sound waves travel through the material being tested. This speed tells with a great degree of accuracy the content and density of the material. This system has been refined to such a degree that it is possible to determine whether rock will have to be blasted or whether it is rippable. Information such as groundwater tables may also be determined by using this method. Geologists are also utilizing the speed of computing systems to perform slope analysis (whether a given slope will be stable in a particular soil type).

Hydrographic investigation and design should be greatly aided by the use of systems such as the Texas hydraulic system. This integrated system provides the engineer with the tools necessary to examine in detail many aspects of a hydraulic system that in the past required many individual computations. This system can be used in simple projects such as the design of culverts or in complex projects such as the design of an entire storm sewer network.

If the plan sheets are prepared by the photogrammetric department, they are taken directly from the manuscripts made from the aerial photographs. Thus all the topographic features are shown as they actually appear. This saves much of the time required for a draftsman to interpret and plot from field notes. At the same time that the plan sheets are prepared, cross sections are taken along the centerline of the project by means of a stereocompiler or a terrain data translator. These sections are punched directly into cards that may serve as input to an earthwork system. The cross sections can be plotted at this time by a plotter driven by a computer so that the designer may have graphic evidence of exactly what he is working with.

In the final design stages, the computer proves most valuable to the design engineer by allowing him to do trade-off studies between optimum design and minimum cost. Ordinarily, the earthwork is the most expensive single item in any roadway contract, and computers are ideally suited to such repetitious tasks as earthwork computation. There are many different earthwork systems currently in use; the capabilities of these systems range from handling simple design to working with complex design. It should be noted that the roadway design subsystem of TIES earthwork design probably has more capabilities than any other system currently in use.

The design engineer, using almost any earthwork system, can include such features as independent horizontal alignment for multilane facilities, independent vertical alignment for multilane facilities, boulevard ditches with independent grades, hinge point method of slope design, and bench slope design in mountainous terrain. The ability to change any or all of the various design features allows the design engineer to obtain rapidly an estimate of the cost of these changes. One study that is frequently used is slope design as opposed to guardrail warrant, i. e., whether it is more economical to flatten fill slopes to eliminate guardrail or to install the guardrail. This analysis is made possible by a guardrail program that is usually a subsystem of an earthwork program and that bases guardrail warrant on embankment geometry as outlined in National Cooperative Highway Research Program Report 54.

The design engineer may also experiment with various vertical and horizontal alignments in order to obtain a roadway that operates as freely as possible. The North Carolina State Highway Commission in cooperation with North Carolina State University is studying a roadway simulation system that will allow the engineer to determine and change the operational capacity of a proposed roadway.

All of the information pertaining to a stretch of road, including information such as vertical alignment, horizontal alignment, design speed, and vehicle loading, is entered along with the time interval at which checks are to be made. The output of the program gives the following information: (a) the number of vehicles that have entered the system, (b) the number that have left the system, (c) the number that have passed other vehicles successfully and the number that have failed, (d) the speed of the various vehicles, (e) the headway of each vehicle, and (f) the number of accidents. When the data were tested against actual conditions, it was found that vehicle flow as simulated by this program was very close to actual flow. Programs such as this will allow the designer to measure the effectiveness of a proposed roadway and will allow him to experiment with options that may result in more efficient operation.

After all the design is completed, the right-of-way and construction limits are plotted on the plan sheets. Individual property plots can also be plotted at this time, and in some states these individual plots may serve as legal documents. The right-of-way takings may also be computed at this time. All of these plots and computations must rely on horizontal alignment systems that range in complexity from very simple ones that handle only straight-line work to very complex ones that have the capability to handle spiral curves.

Many states are utilizing the storage and recall power of the computer to keep up with the progress with which right-of-way is being acquired. This gives the right-of-way engineer a powerful tool in making determinations of where additional effort must be applied in order to keep the acquisition of right-of-way on schedule or, in rare instances, to push the letting date of a project ahead because of the entire right-of-way being acquired ahead of schedule.

Computing systems are also used in Pennsylvania to make predictions as to how long the right-of-way acquisition for a particular project will take and how much this acquisition will cost. These predictions are based on a data bank of right-of-way information accumulated in the past and constantly being expanded.

Some states have systems that maintain the current status of all projects. This includes the number of man-hours that have been worked on the project by each job position, which is taken directly from payroll cards. A system such as this, a right-of-way program such as that used in Pennsylvania, and remote terminals would allow the engineer to know instantaneously the progress of a project. Bridge design and final roadway design can proceed simultaneously.

Engineers in New York have been working on the bridge design segment of TIES and have developed an integrated bridge design system that will do most of the design work and some of the plotting for relatively simple bridges. Although this system handles only about 20 percent of the bridges designed currently, it is expected to handle about 80 percent in the near future. Eventually this system should be applicable to all states. Each of the seven major programs in the system can be used separately.

Programs are typically used for the following: establishing span lengths, working horizontal and vertical layouts, designing beams or girders, designing bearings, designing piers or abutments, and working all kinds of elevations. Layout and elevation programs will handle bridges on any combination of tangent, spiral, or circular curve, with variable rates of superelevation and grades or vertical curves. Beam design may be used for simple or continuous spans, composite or noncomposite, steel I-beam, plate girder, or prestressed concrete. Piers may have multiple columns or a hammerhead design with one column. Superstructure construction elevations can be given for beam lines, overhang lines, and header lines. Reinforcing steel may also be worked and printed for inclusion in the final plans.

The Illinois Division of Highways is in the process of developing a computerized highway bridge rating system. This system, through computer analysis, will allow

structural engineers to conduct inventory and operational bridge ratings. Bridge ratings indicate the load-carrying capacity of a structure after an analysis has been conducted by using a truck load and axle configuration. The rating system also will enable engineers to automatically re-rate structures when changes in bridge use or condition occur. This is particularly important because legal load limits may change sometime in the future.

Pavement design is another area in which the potential of automated systems is just beginning to be used. The Center for Highway Research at Austin is currently working on a pavement design system that should prove most helpful. In this system, the pavement design engineer enters information concerning traffic, materials, maintenance, and construction as input, and a variety of pavement designs that meet the requirements are returned along with their anticipated cost and life expectancy.

Once the entire right-of-way has been acquired and the final design is complete, the final plans must be prepared for the letting of contracts. At this time, all automated systems are aimed at providing the contractor with the information he needs in order to bid on the job and the resident engineer with the information he needs to oversee construction of the job.

After the final pavement design is selected, the earthwork system must again be used to secure a final earthwork listing. This listing may contain information such as shoulder and ditch elevations and other information that may not appear on the preliminary earthwork listing. An earthwork subsystem that is also used at this time is the mass diagram plot, which aids the contractor in establishing haul lines, determining borrow pit locations, and locating areas for the disposal of waste material.

After all the quantities are computed and all the information necessary to construct the project is collected, the proposal is assembled, and an engineer estimates the anticipated cost of the project. Equitable prices for the various items in the contract are arrived at in North Carolina by using a bid average prices program as a subsystem to the bids program. These averages are categorized by type and location and usually afford an excellent basis for arriving at a price for any item. It is now economical to estimate the cost of each component project and then, by using the computer, combine these estimates into one combined estimate.

A most important part of any contract or proposal is the project's special provisions. Because these provisions are often the same for similar projects, this is an area that lends itself readily to an automated system. In North Carolina, we are using a magnetic tape typewriter system for writing these special provisions. Each special provision carries a code letter and a number; therefore, when the proposal is being written, the provision can be called by code number and automatically typed into the proposal. This system decreases the need for extensive proofreading and thus considerably speeds up the work of the plans and proposal section.

Along with the preparation of the proposal, some states are using the critical path method to determine such information as early and late start calendar dates, early and late finish calendar dates, and the critical path.

On the day that bids are opened, the computer is used to extend all computations in the contract and to print out a listing of all the bidders and their bids on the various items in the contract. An analysis is also made between the engineer's estimate and the low bidder on each project, and the percentage difference is tabulated.

After the contract is awarded and before construction actually begins, the resident engineer may make use of a system such as North Carolina's construction elevation program that provides the resident with elevations of up to five points to each side of the centerline of a typical section. These elevations may be obtained at any interval desired; 25 ft is the distance most often used. The input consists of the grades, typical section, superelevation, and tangent runout for the project. This system has greatly reduced the tedious process of computing offset elevations, particularly in superelevated sections.

While the project is being constructed, monthly estimates for the various items in the contract are prepared so that the contractor may be paid for work that has been accomplished. Such a system is now used in Connecticut and is expected to be used in North Carolina. This is an application to which computers are readily adapted,

and an application that can save much laborious hand calculation. When the project is completed, these monthly estimates can be combined into a final estimate and the contract settled more quickly than with the methods currently in use.

Photogrammetry is also used at the end of a job. Studies have shown that earth-work computations from aerial photographs are as accurate as computations based on cross sections taken in the field by hand. As a project is cleared, it is flown and photographed for original sections. Controls are established both vertically and horizontally by the use of panels at frequent intervals. The original sections are compiled and punched into cards and, after being edited, are stored until the grading of the project is completed.

After grading has taken place, the project is flown and photographed again. These as-graded photographs are used for the taking of the final sections. Two methods of taking final sections are used in North Carolina. The first is the taking of the entire section on projects that are to be graded only; the second is for the resident engineer to supply the template or subgrade sections on a project that is being paved and for the photogrammetric department to supply the balance of the section from the ditch out to the tie points. The North Carolina final estimate volumes program will handle sections that are entirely taken in the field, sections taken by photogrammetric methods, and a combination of the two. The final estimate volumes program will compute excavation and embankment quantities and borrow pit calculations.

AUTOMATED ROAD DESIGN

Larry G. Walker, Texas Highway Department

The end product of road design is a safe and adequate highway that serves the transportation needs of the public without seriously disrupting the environment. The more immediate product of road design is a set of plans and specifications that represent a dimensional and qualitative description of the road to be constructed.

Two basic resources are provided to a contractor who is preparing to build a highway: plans and specifications and the procured and cleared right-of-way. These resources answer three important questions for him; they tell him how, how much, and where. A long, complex sequence of investigations, computations, decision, negotiations, and graphic and written documentation must be made to answer these questions. Each of the steps in the sequence can be accomplished by manual methods, but modern technology can automate many of these steps.

Electronic computers are properly thought of as the primary method of automation. This is particularly true in computational or data manipulation activities that are prevalent in roadway design. For purposes of this discussion, however, I would like to define automation as any mechanized tool that augments or eliminates manual processes. Thus, any equipment is considered an automated device that can assist in acquiring, comparing, and manipulating data; facilitate decision-making; or represent either graphically or verbally roadway design information pursuant to the cleared right-of-way and the plans and specifications.

This rather broad definition of automation extends the range of possibilities for automating the various phases of the road design activity. The decision to automate a process should not be based on the availability of automation; it should be based on whether automation can bring about a definable design benefit. Any automated step is accompanied by expenditure and must be evaluated on the basis of significant return on investment in the form of more productivity from engineering and support personnel; improved and optimized designs resulting from the ability to make more design trials with the same personnel; shorter time to completion in various design phases; reduced cost of the design phase; and lower construction costs achieved through optimization. The important consideration is that automation must buy something. This does not always come in the form of reduced cost, but it must be in real, identifiable benefits that produce a definite return on investment.

The spectrum of activities in roadway design is indeed extensive. At one end of the spectrum are the answers to how, where, and how much. At the other end are many factors that generate a need for the road and many constraints that are imposed on the final design by existing conditions. There is a set of processes involved with the study and analysis of traffic demands and requirements that provide input to roadway design. These processes have been automated to a large degree, and the results of this automation are passed on to road design processes. This phase, however, is not considered within the scope of this paper.

When the need for a road begins to be identified, a host of pre-existing constraints is immediately imposed on the where and sometimes on the how and how much. These constraints include physical terrain features, prior construction, and a wide variety of socioeconomic factors. Some attempts have been made to apply automation to the acquisition of these data and the analysis of these constraints. Success to date is limited, but opportunities are extensive. This, too, is considered outside the scope of this paper.

The exclusion of traffic studies and socioeconomic constraints still leaves a broad topic of discussion that includes the acquisition of data, the determination of the physical dimensions of both the road to be constructed and the right-of-way, and the documentation of design in written and graphic form.

There are really two distinct phases that should be recognized: preliminary design and final design. The processes are quite similar but the intent varies. Precise dimensions, quantities, and drawings are required in the final design phase; data on existing physical features need to reflect the precision desired. On the other hand, in preliminary design less precision and detail can be tolerated, and less precise physical data can be used. The intent of preliminary design is not to produce contract documents but to evaluate various alternative locations or routes for the highway. This distinction between preliminary and final design must be kept in mind. (This paper will be directed primarily toward the precise final design activity.)

Almost all of the significant automated road design procedures have been developed since World War II. Photogrammetric mapping procedures and electronic distance-measuring devices are the results of the technology developed during that war. Other technological improvements led to the development of digital computers; digital computers then gave rise to a family of digital data acquisition equipment and graphic computer output media. In effect, the digital computer spawned other automation devices that are compatible with it.

The first generation of computers introduced new possibilities for data manipulation and computations. The computation of these computers, though slow compared to current standards, was much faster than that of any prior machine. Repetitive computations could be made at almost unbelievable speed. Computation of earthwork cut and fill volumes was one of the first automated road design procedures. The big problem was not the computation but the movement of large volumes of data and design parameters to and from the computer. It was also difficult to change from one computing task to another and even more difficult to string a long series of different types of tasks together.

The second generation of computers introduced better input and output devices, better means of switching from task to task and stringing tasks together, and auxiliary storage in the form of tapes that allowed data to be held for future reference within a sequence of computations. With these advances, more features and capabilities were added to computer earthwork programs; programs became more sophisticated; and the integrated system concept was born. This concept seeks to minimize input to the computer and to maximize output from it. This is accomplished by arranging sequences of computer programs and passing data between them in compatible format without the need for output and input between processes.

Third-generation computers, which have better operating systems to accommodate the systems concept and direct access storage devices to make systems more flexible, advanced these techniques.

Unfortunately each new generation usually necessitated redevelopment or extensive conversion of existing programs. Sometimes the new computer was used inefficiently to simulate the old computer process. In each generation, the development activity was repeated over and over because of incompatibilities among equipment. As an example of this wasteful repetition, a recent computer journal placed the number of computers used for commercial applications at 40,000. It then asked the reader to estimate how many programs might have been produced for a typical commercial application, the payroll check-writing program. The astounding answer quoted was more than the population of commercial computers.

Current systems for road design are far more sophisticated than their predecessors, the stand-alone programs. They do the same things much faster and much more flexibly, have many more features, are easier to communicate with, and make better use of output devices. Notable among these are ICES developed by M. I. T., UNMES developed and expanded in a cooperative effort by a number of western states, the TIES roadway design subsystem developed by the Texas Highway Department in cooperation with the Federal Highway Administration, and the BECOM system developed by a French consulting firm. Each of these is committed to the system concept and to the use of third-

generation computer equipment. Each, of course, has advantages and disadvantages and directs emphasis to certain phases of design. Similar systems have been developed by a number of state highway organizations and consulting engineering firms in this country, and significant parallel efforts have also been made in several foreign countries. It is of particular interest that many of the advances in automated equipment, other than the computer, have originated in Europe.

The TIES roadway design subsystem is a good example of automated road design. This system was designed to use not only the computer but also any automated process that produces a return on investment for the road designer. It is committed to the system concept of integrating the flow of data through the various processes with minimum manual intervention. It features program modularity, computer equipment independence, compatible high-level languages, data structuring techniques, code efficiency, automated data acquisition, and input-output media.

The TIES roadway design subsystem integrates more than 200 computer processes that are placed at the designer's disposal to be used in any combination or sequence to achieve the desired results. All of these processes work with an integrated data base that serves the function of data transfer between processes. This data base or file also serves as a dynamic project record. Figure 1 shows the major capabilities that are integrated with the project data base. Although the subsystem is strictly automated, it was designed to take advantage of all available automation tools and to integrate their capabilities with that of the computer. This integration will be shown by discussing both the computer and noncomputer processes.

The entire field of aerial photography and photogrammetry is one of the foremost areas of automated road design. Remote sensing is a new, related field that is beginning to be used by road designers; interpretation of aerial photographs and mosaics has for a long time provided the designer with a useful tool for reconnaissance in preliminary location studies.

Photogrammetric mapping is a new and indispensable tool of the designer that allows him to make precise measurements and representations. It reduces the work of the surveyor, designer, and draftsman by making available extensive data without the need for extensive ground surveying. The ground surveying required for photogrammetric mapping is called control. The complete control data include accurately located points in each photograph to ensure proper measurements from stereoscopic models.

Several automated tools are available to assist in establishing the necessary ground control. One of these is an electronic distance-measuring device that can be used to eliminate tedious ground measurements. The computer system includes processes for reducing both electronically measured distance readings and precise angle measurements. In the process of reducing these automated field measurements, the system stores the resulting data for future design processes.

A control traverse serves not only as orientation for the photogrammetric mapping but also as the backbone of the entire road design process. The computer system is again used to analyze and adjust the angle and distance data in the control traverse and to reduce and store all traverse points and relate them to both the state plane coordinate system and a surface plane. Data thus stored are available for any purpose.

By using electronic distance-measuring equipment, we can save time by spacing the points on the control traverse at greater distances. Other automated tools can be employed to supplement the traverse so that control points are available in each photograph. A stereo analog device such as the Zeiss stereoplanigraph can mechanically bridge several photogrammetric models to supplement the control traverse. Another approach is the use of monocomparators and stereocomparators such as the Zeiss stereocomparator to make measurements on individual photographs. The computer system can then be used to mechanically perform the bridge that is done mechanically by the stereoplanigraph device. In both cases, another computer process of the system is used to adjust the strip of photographs and produce the desired supplementary coordinate points in each photograph.

The full set of control points makes it possible to orient the pairs of photographs to produce stereoscopic models, from which maps can be drawn, and measurements can be made in X, Y, or Z planes. It is here that other automated tools are used. Digital

scalers are available that can make X, Y, and Z measurements directly from the stereoscopic models and record them on cards or other media that are immediately acceptable by the computer.

The Texas Highway Department is currently working on a computer application that is not a part of TIES but that will automate the drafting of maps. Planimetric features will be digitized with an XY digitizer and supplemented by line and symbol codes. The digitizer output will then be input to the computer that will produce automatically plotted planimetric maps. Topographic maps can be produced in a similar manner. When perfected, this system should eliminate considerable manual work now expended in producing photogrammetric maps.

Another extensively used automated data acquisition process is the digitization of terrain data from stereo models. This can be accomplished in either random, grid, or cross-sectional form. (TIES now makes extensive use of cross-sectional data.) In this process, the digital scaler automatically records stations, offset distances, and elevations in computer acceptable media. A computer process is then available to edit and store terrain cross sections and make them available for many subsequent design purposes.

The computer system allows the designer to make use of maps and stored data to establish the final dimensional aspects of the road. The digital plotter, the main auxiliary automation device, is used to complement the computer in almost every process of the system. The designer can make use of any capability in the system in any order he chooses and can accumulate data in the project file and produce a wide variety of plots.

The designer might choose to use the general geometry process. With this, he can use a command-structured input to perform almost any analytical geometry computation using the points that have been previously stored. He can compute and store other points, lines, and circles; compute boundary descriptions and areas; establish parallel or perpendicular lines; and perform many other computations. The results of these computations are stored and are always available for later design activities.

As an example of later use of stored data, the designer might use some of the control traverse points and other computed points to establish horizontal alignments. From coordinate information on PI's and other alignment data, the horizontal alignment process will compute the stationing and properties of horizontal alignments. As many as seven alignments can be computed and stored by this process. An annotated plot of alignments is easily obtained as a by-product of the process. After alignments are established, the designer might elect to use the terrain plot process to produce profile plots along each alignment. He may also ask for cross-sectional plots of the stored terrain data. He can use these plots to help establish vertical alignments and other design parameters.

The designer would then be in a position to enter vertical alignments, templates, and other parameters that describe the three-dimensional aspects of a road. The data thus entered are edited and stored by a unique scheme for storage and retrieval, the design data edit and store process. This process formats the data such that they can be used for a number of other processes.

An example of a process that uses previously stored geometry data, horizontal alignments, and other design data is the offset geometry process. It is similar to the general geometry process but can automatically compute coordinates and elevations related to the various alignments. It can also compute elevations on the roadway surface. This process, which is related to alignments, provides a very handy method of computing right-of-way geometry.

Several specialized processes are also available for use after sufficient information is stored. The general plot processes are used to produce complicated plots that display the geometry that has been computed. These are controlled by the system user.

The alignment relation process computes the relations between pairs of alignments and makes the computed information available for earthwork design at a later stage.

The roadway elevations process produces extensive listings of elevations at requested offsets and station sequences and is used when a large number of elevations are needed. The geometry process is used when single elevations are needed.

The earthwork design process is the workhorse of the system. It combines all of the pertinent stored data concerning terrain cross sections and design parameters into complete design cross sections and up to six roadways having independent vertical and horizontal alignments connected by medians and intersected with the terrain. Special ditch grades and bench grades can be introduced into both median and side-slope design. The process uses an efficient single-pass design procedure that makes use of a unique data structure.

The design plot process provides for plotting design cross sections with or without the terrain cross sections and for plotting of design vertical alignments.

The volumes and mass ordinate process is a report generator that provides summaries of volumes and mass ordinates for all alignments or for selected alignments in accordance with the designer's request.

The haul computations and haul diagram plot processes use the mass ordinates that have been compiled to compute haul quantities and produce a plot of the haul diagram.

At the completion of the earthwork design phase, all information required for producing perspective views of the roadway from any vantage point is available. The perspective plot process converts design cross sections, vantage points, and other plot parameters into a format required to interface with the perspective plotting routines being developed in Region 9 of the Federal Highway Administration.

The integrated file structure of the roadway design subsystem records all pertinent design data and makes them available through the auxiliary graphic and printed reports process for any type of graphic or printed report that may be desired. A number of such reports are currently included in the system. Many others are planned and should be easily accomplished. All of the graphic and printed report features of the system are designed to assist the user in arriving at his final design and in producing the required documents. The digital plots are particularly advantageous here and may be used in connection with another automated procedure, the engineering reproduction procedure, which uses camera reduction techniques for making composite drawings that become a part of the plans. A wide variety of engineering reproduction techniques are available for automation of highway plan production.

All of the data either input, computed, or captured for storage in the road design subsystem may be classified in one of three categories:

1. Tabular data that can be stored and retrieved by table number;
2. Data that are related to specific terrain cross-sectional stations (all of these data may be stored and retrieved by station number with retrieval beginning at any selected station and continuing sequentially); and
3. Data that cover station ranges for one or more separate alignments and that include horizontal alignment, vertical alignment, template, slope selection criteria, median, special ditch grades, and other similar types of data.

Each type of data in the last category covers a range of stations. The problem of storing and recalling is further complicated because the station ranges are not related to the different kinds of data. This nonhomogeneous nature is shown in Figure 2.

The design data edit and store process uses the "design data block concept" to provide a unique method for storing and retrieving data. It simply compacts all of the various kinds of data into a certain size block; when the block is full it keeps track of the stations covered by the block (Fig. 3). Then, when any type of data is required for a certain station, this system can retrieve the proper block and all the required data can be automatically extracted as required by a system utility routine. This concept makes the single-pass design possible.

In addition to tailor-made data structuring, the TIES roadway design subsystem uses modularity to achieve a flexible system. If a design procedure changes or another state uses a different procedure, the affected module or modules can be easily replaced without disrupting the system. The use of system utility modules greatly facilitates the addition of new processes to the system. As an example of this, it is never necessary to develop new elevation computation routines. A system module is available for this computation. The control driver is constructed such that it can be expanded to accept new processes.

Figure 1. TIES roadway design subsystem.

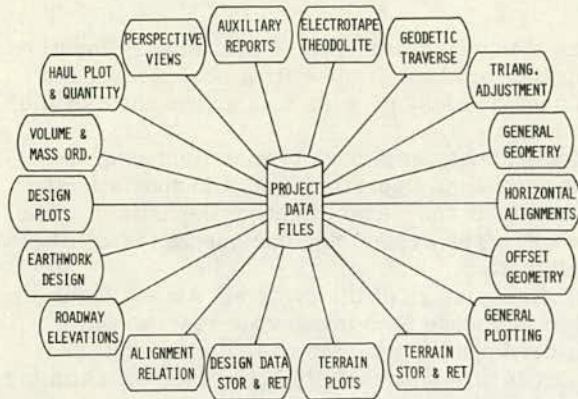


Figure 2. Station range data (data nature).

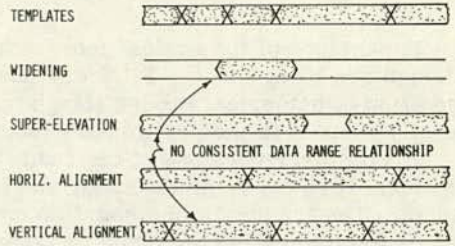


Figure 3. Station range data (design data block).

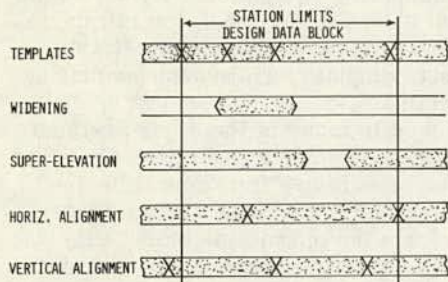


Figure 4. PROMPT terminal.

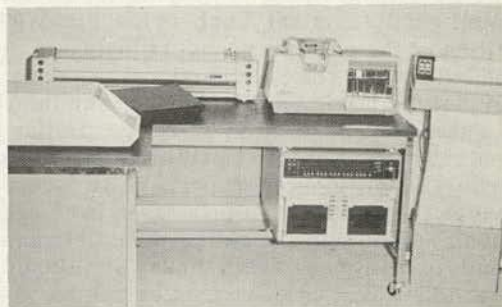
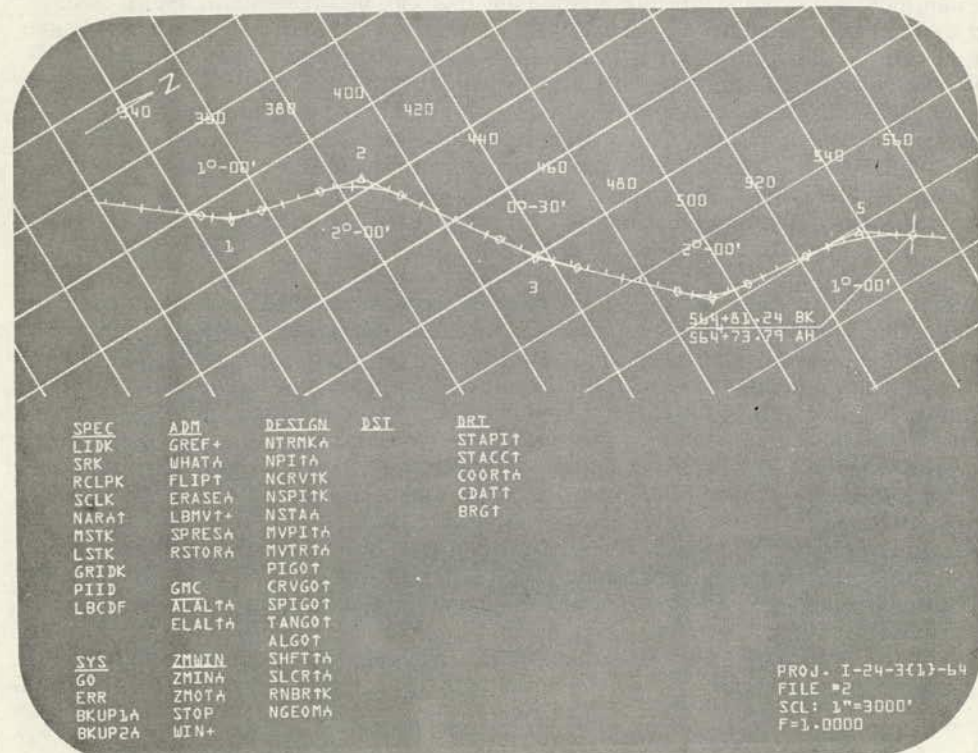


Figure 5. Interactive graphics display.



Expansions of the system into the areas of bridge geometry and preliminary location design are being made. TIES was developed to produce precise final designs, but the addition of numerical ground image techniques and less precise data approaches should easily adapt it to the preliminary location phase.

Preliminary versions of the roadway design subsystem have been delivered to the Federal Highway Administration and to the Oklahoma Department of Transportation for tests. Testing and implementation continue within the Texas Highway Department, and plans for testing in California are being made. The system and documentation will be distributed by the Federal Highway Administration.

A form of automation will be used for training users of the system. An audio-visual overview of the system is being prepared to introduce it to prospective users, and a self-instructional training course is being developed to give the user a more detailed view of the system. This method of training is now successfully being used on a similar system.

One other automated tool should be discussed in connection with the TIES roadway design subsystem. As is the case in many states, road design in Texas is performed in a number of decentralized locations. In these cases, it is difficult to automate the process without the use of sophisticated data communications equipment. By use of an "intelligent" terminal, such as the PROMPT terminal shown in Figure 4, the full capabilities of the computer system including plotting are available at the remote station. The bulk of the computational work is done by the host computer, while data formatting and plot formatting are handled by the intelligent terminal.

Features discussed in TIES are similar to those used in many of the other systems mentioned. All of the capabilities and uses of automated equipment are currently being used. In fact, most of the capabilities described have been in use for some time individually. In TIES the processes have been integrated and linked with system techniques, utilities, and a tailored data structure to perform the operations more efficiently. In almost every case, significant return on investment had already been established, and an even greater return on investment can be expected by using the systems approach. Many opportunities exist for refinement and integration with automated devices that are currently available or that might be available in the future.

The subject of automated road design should not be concluded without a look into the future. The most significant future development that can be foreseen is use of interactive graphic design techniques. Practically all current computer systems are based on batch or remote batch processing in which all input is entered at one time and all output is received in a batch. Interactive graphics will give the designer an opportunity to intervene in the process. He will do a part of his design and review the results graphically on a video terminal. This process will be repeated until he is satisfied with the overall design. This type of approach is now used in the interactive design of such things as electronic components and ship structures. The use of interactive graphics in highway design applications is currently being investigated by the Control Data Corporation under the sponsorship of the National Cooperative Highway Research Program and also by the California Division of Highways. The findings of both organizations indicate that interactive graphics is feasible and practical for highway design.

An interactive graphics road design system would do the same things that current design systems do, but interactive graphics would provide a two-way method of communication between the designer and the computer. Responses of the computer are almost immediate and are in the form of line drawings and character images displayed on a television-like screen (Fig. 5). The designer communicates by use of a typewriter keyboard and a light-sensing pen that allows him to indicate desired actions by pointing at a list on the screen or by pointing at segments of the drawing that are to be revised or acted on.

The designer may control a wide variety of display views and change design parameters. For example, to direct the computer to shift a PI he would point to a command name and the selected PI, both of which are displayed on the screen, and then move the pointer to a new location.

An NCHRP report (1) gives a very complete description of this subject along with the basic design requirements of such a system and an evaluation of the costs and bene-

fits that might be obtained. The TIES roadway design subsystem was studied extensively as a part of that project, and the system's capabilities, data structuring, and modularity were judged to conform to the basic requirements of an interactive system. The project advisory committee approved a recommendation that the TIES roadway design subsystem be used as the application system for further project development. In this concept, the interactive system and terminal equipment would, in effect, become a communications channel linked to the roadway design subsystem.

REFERENCE

1. Interactive Graphic Roadway Design System. NCHRP Project 20-8, 1972.

TEXAS HYDRAULIC SYSTEM

Dwight Reagan, Texas Highway Department

The Texas hydraulic system (THYSYS) is an integrated system of hydraulically oriented computer routines specifically designed for the solution of highway hydraulic problems. The input and output of the system are geared to the requirements of the Texas Highway Department.

In the past, a number of individual computer routines were available whereby the engineer could solve many individual hydraulic problems. However, a hydraulic design or analysis problem cannot be solved in one step. A group of interrelated calculations is required for the complete solution. This requirement and the need for optimization are the basis for THYSYS. THYSYS was designed to incorporate and use as many existing hydraulic computer routines as possible.

The driver and skeleton of the system are modular; particular routines useful to the Texas Highway Department may be replaced by alternate routines or procedures that might be more useful to another user. The system is documented to the extent that the user need only know what procedure he wishes to use for a particular function. The documentation gives directions pertaining to input and output so that the user may remove the unwanted routine and replace it with one of his own. General documentation is currently available, and detailed documentation will be available in the future.

The input forms present to the user, in familiar terms, all options available (Fig. 1). He merely chooses an option. This method eliminates the need for a high degree of engineering sophistication by the user and allows for broader use by technicians. This style is used in THYSYS in lieu of the command-structured, problem-oriented style used in the Integrated Civil Engineering System.

The computer output is tailored directly to Texas Highway Department needs and requirements. All outputs have been designed in the interest of uniformity and completeness. The output format may be easily adjusted to conform to the needs of any other organization.

THYSYS is composed of a main driver system and 5 basic subsystems (Fig. 2). These 5 subsystems are HYDRO, the discharge determination function; HYDRA, the channel analysis function; CULBRG, the structure analysis and design function; SEWER, the storm sewer analysis and design function; and PUMP, the pump station analysis and design function.

HYDRO, HYDRA, and CULBRG are written so that they may be used in concert (Fig. 3). For instance, without user direction, the discharge may be passed into HYDRA for use in determining a tailwater elevation, and these two items, in turn, may be passed into CULBRG for use in a structure design. A number of other combinations are possible, and each subsystem can be used by itself. SEWER is completely self-contained and is not used in combination with any of the other subsystems.

An extensive data auditing and management scheme is incorporated into the system. All data for a problem are read into the system, and discernible errors are noted. In addition, any assumptions made by the system are noted. An echo print of all input data is generated for each problem.

Figure 4 shows an echo print of input data for a box culvert design, and Figure 5 shows the output for that data indicating the various designs tried and the final accepted design.

Figure 1. Typical input form.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Cross out one										Design: Cross out one or neither										Specify opening configuration. Cross out one.										Prob. #																																																																					
CULBRG	DESIGN	ANALYSIS	BOX	CULVERT	SINGLE	MULTIPLE																																																																											Number																		
This card is necessary only for values not supplied from other subsystems. (HYDRO or HYDRA)																																																																																																			
SUPPLY Q=	CFS	TW ELEV =	FREQUENCY =	YRS																																																																																															
CLVRT	CIRCULAR	ARCH	RIVAL	BOX	CONCRETE	CGMP	PLATE																																																																									"a" value																			
CLVRT	STRAIGHT	BROKEN	BK	STEPPED	FLARED	DRAPI	INLT	NORMAL	KE=																																																																							"a" value																			
CLVRT	OUTLT STA	Design: Station at toe along L of structure	Design: Elev of toe	Design: Station at toe along L of structure	Design: Elev of toe	Design: Station at toe along L of structure	Design: Elev of toe	Design: Station at toe along L of structure	Design: Elev of toe																																																																						"a" value																				
CLVRT	BREAK STA	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation																																																																																										
CLVRT	BREAK STA	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation	Design: Stationing along centerline of structure	Design: Break elevation																																																																																										
CLVRT	MAX HEADWATER ELEV	Design: Maximum headwater upstream of culvert	Design: Elevation	Design: Maximum headwater upstream of culvert	Design: Elevation	Design: Maximum headwater upstream of culvert	Design: Elevation	Design: Maximum headwater upstream of culvert	Design: Elevation																																																																																										
CLVRT	DIMENSIONS	Design: Required entry for the culvert	Design: Culvert diameter (in.)	Design: Culvert rise	Design: Culvert span	Design: No. of culvert barrels																																																																																													
ROAD	UPSTRM SS	Design: 1	DNSTRM SS	Design: 2	MAX DEPTH =	BARRELS =																																																																																													
BROG	MAX AVERAGE VELOCITY	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge	Design: Minimum allowable average velocity through bridge																																																																																										
BROG	LEFT SIDE	Design: Left header slope	Design: Right header slope	Design: Insert one: UP or DN	Design: Orig. sec. ID if skewed																																																																																														
FL-OV	SEFX	Design: Cross-section ID	Design: Distance along cross-section	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST																																																																																										
FL-OV	SEFX	Design: Cross-section ID	Design: Distance along cross-section	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST	Design: TO X DIST																																																																																										
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Supply job number for culvert if plan summary desired																																																																																																			
JOB NO.	IPE 567																																																																																																		
ENDATA																																																																																																			
PLAN SUMMARY																																																																																																			

Figure 2. Texas hydraulic system.

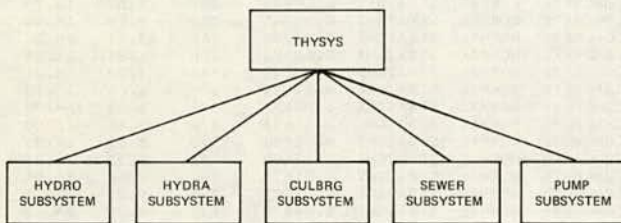


Figure 3. Data exchange paths in THYSYS.

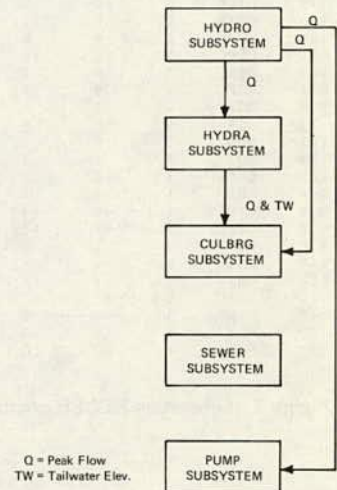


Figure 4. Echo print input.

```

$STA 907+50
$WB LANE
CULBRG DESIGN CULVERT SINGLE 7A567
SUPPLY Q= 1743 CFS TW ELEV = 2506.04 FREQUENCY = 50 YRS 7A567
CLVRT 907 BOX CONCRETE 7A567
CLVRT 907 STRAIGHT NORMAL KE=015 7A567
CLVRT 907 OUTLT STA 289 EL2499.59 INLET STA 101 EL2500.00 7A567
CLVRT 907 MAX HEADWATER ELEV 2508.00 MAX OUTLET VELOCITY 10 FT/SC 7A567
ROAD 907 UPSTRM SS 2 DNSTRM SS 2 MAX DEPTH= 7 7A567
JOB NO. IPE 567 7A567
ENDATA 7A567
CULVERT FEASIBILITY ROUTINE NOT AVAILABLE
    
```

Figure 5. Echo print output.

DESIGN SINGLE OPENING CULVERT JOB NUMBER= IPE 567
 CULVERT ID = 907
 DESIGN FLOW = 1743.0 CFS FREQUENCY = 50 YEAR
 TAILWATER ELEVATION = 2506.04

BBL S	DIAM	WIDE	HIGH	LENGTH	ALLOW. HW ELEV	CALC. HW ELEV	CALC. HW	ALLOW. VELOC.	CALC. VELOC.
3	0	9	7	160	2508.00	2508.16	8.19	10.00	10.01
4	0	7	7	160	2508.00	2508.06	8.09	10.00	9.65
3	0	10	7	160	2508.00	2507.75	7.78	10.00	9.01

INLET STATION = 115 ELEVATION = 2499.97
 OUTLET STATION = 275 ELEVATION = 2499.62

SLOPE	PROFILE	BARREL MATERIAL	SHAPE	INLET TYPE	KE
0.00218	STRAIGHT	CONCRETE	BOX	NORMAL	0.150

Figure 6. Summary of culvert design and analysis.

SUMMARY OF CULVERT DESIGN/ANALYSIS

JOB NO. IPE 567

CLVRT I.O.	BBL SHAPE	BBL S	WIDE	HIGH	LENGTH	CULVERT MATERIAL	TYPE INLET	PROFILE	SLOPE	Q (CFS)	CALC HW	CALC VELOC
792	BOX	1	9	5	108	CONCRETE	NORMAL	STRAIGHT	0.00874	296	5.06	13.39
792	CIRC	2	60	60	108	CONCRETE	NORMAL	STRAIGHT	0.00874	296	5.24	12.73
792	CIRC	2	60	60	108	CONCRETE	FLARED	STRAIGHT	0.00874	296	5.07	12.73
860	BOX	2	5	3	203	CONCRETE	NORMAL	STRAIGHT	0.05345	162	3.16	19.94
889	BOX	1	9	8	347	CONCRETE	NORMAL	STRAIGHT	0.02092	960	12.22	25.28
901	CIRC	1	42	42	188	CONCRETE	NORMAL	STRAIGHT	0.00426	108	6.88	11.84
907	BOX	3	10	7	160	CONCRETE	NORMAL	STRAIGHT	0.00218	1743	7.78	9.01
941	BOX	1	9	5	115	CONCRETE	NORMAL	STRAIGHT	0.01331	374	6.08	15.73
965	BOX	4	7	3	123	CONCRETE	NORMAL	STRAIGHT	0.03678	572	3.83	17.78
21	BOX	1	5	4	169	CONCRETE	NORMAL	STRAIGHT	0.03821	224	7.46	21.80
102	BOX	5	9	5	379	CONCRETE	NORMAL	STRAIGHT	0.02149	1570	5.27	19.98
120	BOX	4	6	3	370	CONCRETE	NORMAL	STRAIGHT	0.03480	580	4.52	20.35
885	CIRC	1	42	42	261	CONCRETE	NORMAL	STRAIGHT	0.01872	162	9.66	16.94
894	BOX	1	6	3	268	CONCRETE	NORMAL	STRAIGHT	0.01093	249	9.29	16.09
908	CIRC	1	48	48	208	CONCRETE	NORMAL	STRAIGHT	0.04379	171	8.36	23.62
908	CIRC	1	42	42	210	CONCRETE	FLARED	STRAIGHT	0.04379	171	9.00	24.10
936	BOX	3	7	5	99	CONCRETE	NORMAL	STRAIGHT	0.00692	750	5.37	10.03
947	BOX	6	9	7	120	CONCRETE	NORMAL	STRAIGHT	0.00796	3527	8.14	17.70
961	BOX	3	7	3	140	CONCRETE	NORMAL	STRAIGHT	0.00978	594	5.41	13.29
14	CIRC	1	42	42	226	CONCRETE	NORMAL	STRAIGHT	0.00319	87	5.62	10.21
30	BOX	3	5	3	137	CONCRETE	NORMAL	STRAIGHT	0.03815	346	4.31	18.35
58	BOX	1	10	10	256	CONCRETE	NORMAL	STRAIGHT	0.02398	965	10.37	24.92
60	BOX	1	10	10	105	CONCRETE	NORMAL	STRAIGHT	0.00295	993	10.59	14.19

Figure 7. Subsystem SEWER graphic output.

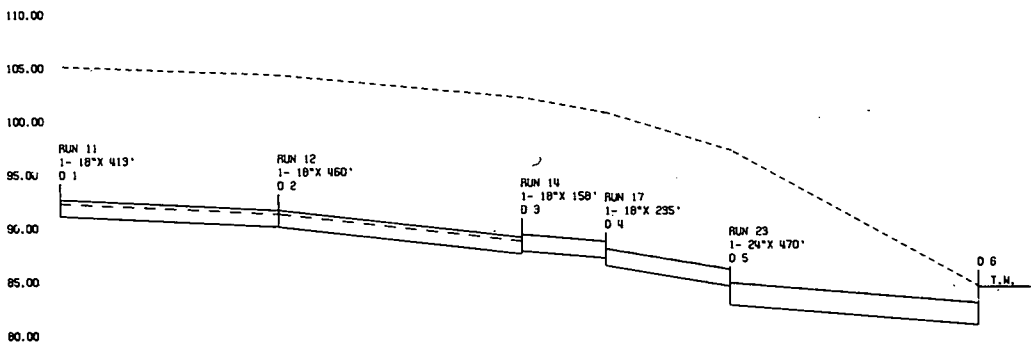
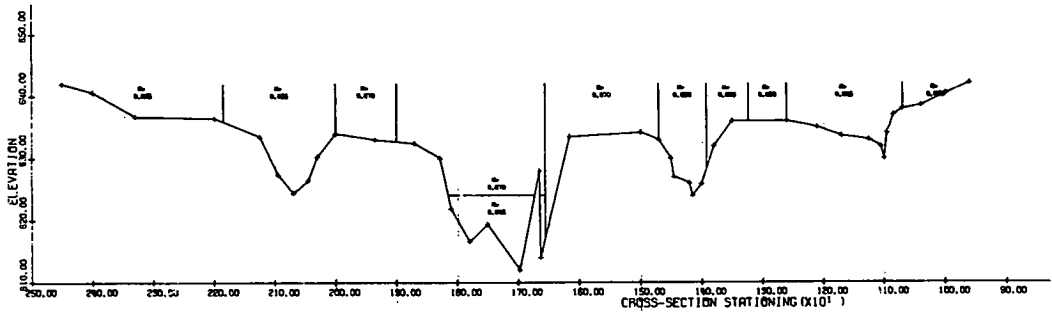


Figure 8. Subsystem HYDRA graphic output.



A feature unique to THYSYS is the "stacking" capability, particularly in the CULBRG subsystem. The first set of input data is submitted in complete form, and a design is the computer output. Then, changes may be made to the original data by reprocessing only those items that change, provided the changed data immediately follow their associated input. A new design is then produced based on the original data and the changes.

CULBRG also has a "plan summary" feature by which basic design data for a computer run are summarized for eventual direct application to the highway plans or for the permanent documentation (Fig. 6). This plan summary is in addition to individual culvert design reports previously generated by the system. This feature provides convenient, uniform, and accurate documentation to the user.

There is an optional graphic output from subsystem SEWER (Fig. 7). Specification may be made for sewer analysis or design and a computer plot of the results. Ordinary computer output accompanies the computer plot. The storm sewer pipe system profile is plotted at standard horizontal and vertical scales, and the computed hydraulic gradient is superimposed on the plot. This graphic output may be applied directly to the plans, with substantial savings in drafting time and expense.

There are many other unique features in THYSYS including the graphic output from subsystem HYDRA as shown in Figure 8. This figure shows a cross section and roughness coefficient boundaries, both vertical and horizontal. (The vertical and horizontal scales may be specified by the user, or a standard set of scales may be used.)

THYSYS has been used extensively in Texas since July 1970 and on a limited test basis for a number of months before that time. The result of this use has been the overwhelming acceptance of the system by field engineers in the Texas Highway Department. Usage leveled out in 1971 to an average of several hundred per month. Particularly heavy use of CULBRG and SEWER has been noted. Because this was expected, emphasis has been directed to completed computation routines pertaining to culvert and storm sewer analysis and design. Obviously, a system of this size cannot be implemented without some problems. THYSYS has been no exception. However, all of the problems encountered to date have been overcome, and development is proceeding. THYSYS now has 70 working subroutines in the system, and important cost analysis routines are to be added in the near future.

A comprehensive user's manual for THYSYS that covers every aspect of required input data has been compiled and distributed. Brief summaries of output and the many possible error messages that may be generated are also discussed. Texas Highway Department personnel have apparently had no major problems in learning to use this system. A self-instructional training manual for the THYSYS computer system has also been compiled, and response to this manual has been very good.

Most of the Texas Highway Department field use of the system is accomplished by mail with the longest delay usually attributable to the U. S. Postal Service. Several urban districts have access to the system through the remote 2,780 terminals. In the near future, these terminals will be located in each of the 25 district offices.

AUTOMATION IN PAVEMENT DESIGN AND MANAGEMENT SYSTEMS

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Center for Highway Research, University of Texas at Austin

Pavement design presents a complex problem that involves a variety of loads, materials, and environments. There are also various economic criteria that must be applied and a number of design details that must be determined in solving a pavement design problem. Existing design methods are generally based on empirical procedures and use models that are based on theory and general experience.

Generally, so-called pavement design methods have concentrated on finding a combination of thicknesses of available materials that will last the intended service life of a facility without requiring rehabilitation. Little attention has been given to required maintenance schemes or to the overall economics of the designed system. Figure 1 shows the general procedural flow of such empirical design methods.

Other details that must be established for a rational design are thickness requirements of various layers, selection of materials, type of pavement and overlays, joint and reinforcement details, and seal coats and maintenance schedules. The computations that are required when these details must be determined for a large number of possible alternatives make it impossible to perform the analysis manually. The use of manual analysis is also impossible when these alternatives must be optimized to achieve the best set of solutions, or resource allocations, and when various decision criteria must be considered.

The initial phase of the overall system design problem is mathematical modeling, which is used to achieve an optimum design configuration. Implementation and feedback are the long-range planned objectives of a pavement management system. When the optimal strategy for a design procedure is implemented, it may produce results that deviate from those predicted. Thus, pavement design must involve a feedback control process that accumulates pavement data on construction, performance, and cost in a pavement system data bank, which is used to modify the pavement design system models. The result is a closed-loop pavement design and management system that can use implementation and feedback data to improve its subsystem models. Figure 2 shows the overall concept of this pavement design and management system.

Solution of the broad problem of pavement design and management requires a computer that is fast and accurate and has large storage capacity. The computer aids the pavement design engineer in several ways:

1. It allows greater use of theory and analytical techniques and, thus, restructuring of the analysis procedures;
2. With the use of suitable models, it makes feasible the consideration of a full spectrum of variables that affect pavement systems;
3. It increases the number of possible designs considered by generating a large number of alternatives;
4. It allows the use of many kinds of constraints and decision criteria;
5. It allows for various optimization techniques that can pick out favorable alternatives and simplify the decision-making process;
6. It can store a large amount of pavement behavioral data that can be analyzed to modify and improve the existing design models; and
7. It provides mechanisms for predicting and managing future designs and economic alternatives for the administrator.

Figure 1. Format of existing design procedures.

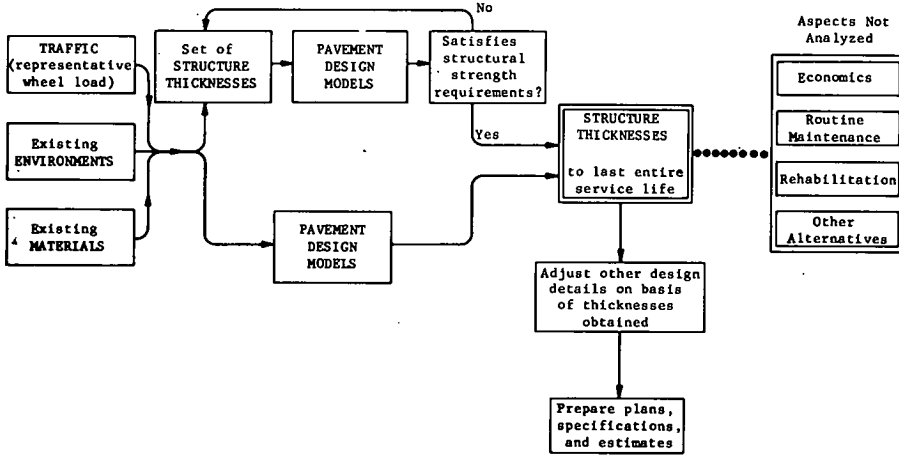
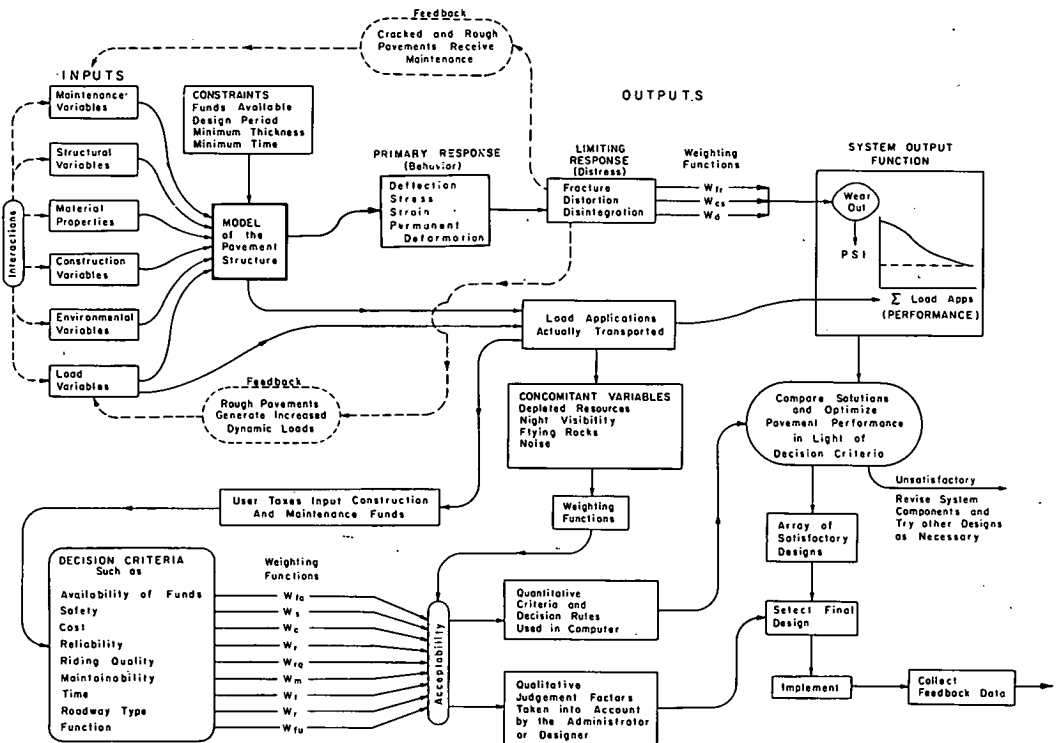


Figure 2. Conceptual pavement system.



AUTOMATED PAVEMENT DESIGN SYSTEMS

The concept previously described led to the formulation of working models for the pavement design system (PDS) (2). The operational systems consist of computer programs in two categories: rigid pavement system (RPS) (3) and flexible pavement system (FPS) (4, 5, 6). The programs are the first iterations of a research study and will be continually improved. The main objective of the computer programs is to use the best information from research on individual subsystems and to provide the decision-maker with a set of feasible design alternatives arranged in order of increasing overall total cost and with other pertinent information necessary for making a rational design decision.

Input and Output of Pavement Design System

A large number of numerical inputs are used for PDS programs. FPS uses about 50 different input parameters, and RPS uses well over 100 parameters. The input for the programs is in the following broad categories.

1. Program controls are used to control the operation and to exercise the options over the solutions;
2. Constraints are used to generate specific types of solutions with respect to thicknesses, time schedules, and funds and to control the number of feasible designs;
3. Traffic volume, growth, and distribution are used to describe the expected traffic that the pavement must serve during its lifetime;
4. Material properties are used to define the engineering characteristics of materials used for subgrades, subbases, bases, surfaces, reinforcements, overlays, and seal coats;
5. Performance variables are used to define the limits on serviceability indexes for an initial or overlaid structure;
6. Material costs are used for computation of the costs of materials and the costs of providing these materials (interest rate and salvage value are used to weight future investments in terms of current worth);
7. Traffic delay variables are used to analyze the costs of overlay construction due to inconvenience to traffic users;
8. Environmental variables are used in structural and maintenance subsystems of the computer programs;
9. Stochastic parameters are used to take into account regression errors of the design models as well as variations of material properties with time and space;
10. Road geometrics are used to define the overall dimensions of the facility to be designed; and
11. Seal coat variables are used to impose specific seal coat schedules for each pavement design.

An example of the inputs echo-printed by the computer for the FPS program is shown in Figure 3.

The prime decision criterion for the selection of the optimal and nearly optimal pavement strategies is total overall cost. Availability of initial funds is another decision criterion, but it also acts as a restraint.

Solution output is intentionally arranged such that the designer can exercise his judgment. It is currently possible to use mathematical formulation to determine the relative importance to the decision-maker of various economic, social, and experience values. A set of alternative design strategies and the information pertinent to them are presented as a summary table arranged in increasing order of the present worth of total overall costs.

General Formulation of Pavement Design System

The computer programs are written to give performance, structural, and economic subsystems and arrays of designs and other pertinent information. A systematic structuring of the operational pavement design system is shown in Figure 4.

Figure 3. Input data (shown as output) for example problem.

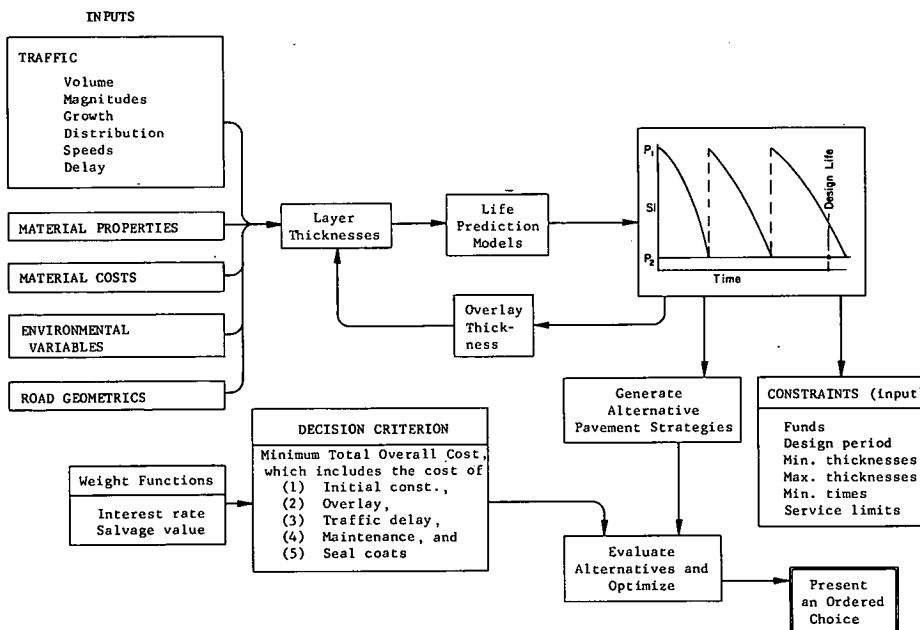
PROB 1 AVERAGE PROBLEM

THE CONSTRUCTION MATERIALS UNDER CONSIDERATION ARE

MATERIAL	COST/C.Y.	ST.COEF.	MIN.DEPTH	MAX.DEPTH
ASPHALTIC CONCRETE	10.00	.75	1.00	6.00
CR. LIMESTONE	5.00	.70	6.00	16.00
GRAVEL	2.00	.40	6.00	16.00
SUBGRADE	0.00	.25	0.00	0.00

NUMBER OF INPUT MATERIAL TYPES	3
MAX FUNDS AVAILABLE PER SQ.YD. FOR INITIAL DESIGN (DOLLARS)	4,000
LENGTH OF THE ANALYSIS PERIOD (YEARS)	20.0
INTEREST RATE OR TIME VALUE OF MONEY (PERCENT)	5.0
ASPHALTIC CONCRETE PRODUCTION RATE (TONS/HOUR)	75.0
ASPHALTIC CONCRETE COMPACTED DENSITY (TONS/C.Y.)	1,80
SALVAGE PERCENT AT THE END OF ANALYSIS PERIOD (PERCENT)	50.0
MAXIMUM ALLOWED THICKNESS OF INITIAL CONSTRUCTION (INCHES)	25.00
DISTRICT TEMPERATURE CONSTANT	25.00
SERVICEABILITY INDEX OF THE INITIAL STRUCTURE	4.2
MINIMUM SERVICEABILITY INDEX P2	2.5
SWELLING CLAY PARAMETERS -- P2 PRIME	1.50
B1	.1000
ONE-DIRECTION ADT AT BEGINNING OF ANALYSIS PERIOD (VEHICLES/DAY)	10,000
ONE-DIRECTION ADT AT END OF ANALYSIS PERIOD (VEHICLES/DAY)	20,000
ONE-DIRECTION 20-YR ACCUMULATED NO. OF EQUIVALENT 18-KIP AXLES	4,000,000
MINIMUM TIME TO FIRST OVERLAY (YEARS)	5.0
MINIMUM TIME BETWEEN OVERLAYS (YEARS)	6.0
MIN TIME TO FIRST SEAL COAT AFTER OVERLAY OR INITIAL CONST.(YEARS)	5.0
MINIMUM TIME BETWEEN SEAL COATS (YEARS)	5.0
A SEAL COAT WILL NOT BE APPLIED WITHIN ONE YEAR PRIOR TO AN OVERLAY	
NUMBER OF OPEN LANES IN RESTRICTED ZONE IN O.D.	1
NUMBER OF OPEN LANES IN RESTRICTED ZONE IN N.O.D.	2
C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE O.D. (MILES)	.50
C.L. DISTANCE OVER WHICH TRAFFIC IS SLOWED IN THE N.O.D. (MILES)	.50
PROPORTION OF ADT ARRIVING EACH HOUR OF CONSTRUCTION (PERCENT)	6.0
OVERLAY CONSTRUCTION TIME (HOURS/DAY)	8.0
THE ROAD IS IN A RURAL AREA.	
PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN O.D. (PERCENT)	5.0
PROPORTION OF VEHICLES STOPPED BY ROAD EQUIPMENT IN N.O.D. (PERCENT)	5.0
AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN O.D. (HOURS)	.100
AVERAGE TIME STOPPED BY ROAD EQUIPMENT IN N.O.D. (HOURS)	.100
AVERAGE APPROACH SPEED TO THE OVERLAY ZONE (MPH)	50.0
AVERAGE SPEED THROUGH OVERLAY ZONE IN O.D. (MPH)	30.0
AVERAGE SPEED THROUGH OVERLAY ZONE IN N.O.D. (MPH)	40.0
FIRST YEAR COST OF ROUTINE MAINTENANCE (DOLLARS/LANE MILE)	50.0
INCREMENTAL INCREASE IN MAINT. COST PER YEAR (DOLLARS/LANE MILE)	20.0
COST OF A SEAL COAT (DOLLARS/LANE MILE)	857.0
WIDTH OF EACH LANE (FEET)	12.0

Figure 4. Structure of working pavement design system.



For initial designs, all possible combinations of the thicknesses of materials are generated, starting with the minimum values and progressing to the maximum ones. When these combinations are considered for different sets of available materials, such as cement concretes, asphaltic concretes, and bases and subbases, a large number of initial designs are produced, each of which is considered and analyzed separately. Each initial design thus produced is subjected to restraints specified by the designer. Some of the important ones are (a) maximum total thickness of initial construction, (b) minimum time to the first overlay after initial construction, and (c) maximum cost of initial construction. If an initial design does not satisfy any one of these three restraints, it is rejected. The designs that do meet these restrictions are considered to be feasible initial designs and are analyzed further. For the rigid pavement system, reinforcement and joint spacings are computed for each of the initial designs.

An initial design that does not last the analysis period but meets all other feasibility requirements is overlaid. The types of overlay provided are flexible over flexible pavements, flexible over rigid pavements, and rigid over rigid pavements. Minimum thickness of the overlay and maximum combined thickness of all overlays are specified by the program user. If a strategy requires its next overlay before the minimum specified time between overlays, it is abandoned. Figure 5 shows how the restraints are applied for the initial designs. Figure 6 shows the techniques built into PDS programs for ascertaining general overlay performance patterns but does not represent an actual problem. The relative differences in the performance patterns of initial designs with low, medium, and high structural strengths indicate that there can be numerous overlay policies for an initial design.

The cost of materials, construction, and maintenance is computed for each successful strategy that meets, along with other constraints, the requirement of lasting for the desired service life. Various costs computed for the pavement design system are as follows (cost computations for FPS and RPS are slightly different because of their structural requirements): subgrade preparation; subbases, bases, surfaces, reinforcements, joints, and tie bars; initial construction; overlay construction; traffic delay during overlay construction; maintenance; seal coat; salvage value; and design per square yard of the pavement.

All costs to be incurred in the future are discounted to their present values by using the interest rate specified by the designer. Overlay, traffic delay during overlay construction, and seal coat costs are the sums of all such costs incurred during the service life discounted separately from the time that they are incurred. Maintenance cost is the sum of each year's separately discounted maintenance cost. Salvage returns are discounted from the end of the service life.

Computer storage is a considerable problem in pavement design systems. The programs are designed to consider a large number of initial designs and overlay strategies. The large volume of pertinent information accompanying every strategy makes it necessary at times to store large arrays of data.

Scanning and optimization are time-consuming operations of the PDS solution process. Various optimization techniques have been used in different versions of FPS and RPS to optimize for the best strategies. Linear programming has been utilized in certain cases. For some versions of PDS, a brute-force method of analysis has shown good results as compared to more advanced techniques of analysis. At present optimization is carried out with respect to costs of the strategies, but in the future other decision criteria will also be built into PDS programs.

The information that the designer must have to investigate a variety of pavement strategies is printed as an output at the end of the problem analysis. A summary table giving as many nearly optimal strategies as specified by the designer is printed. These strategies are printed in the increasing order of total overall cost. This output is the result of optimization carried out among all the designs of every possible and feasible combination tried, including the designs that do not need overlays. The first design of the summary table is therefore the most economical design possible for the given input. Figure 7 shows an example summary table for the rigid pavement system program.

Figure 5. Application of restraints to initial designs.

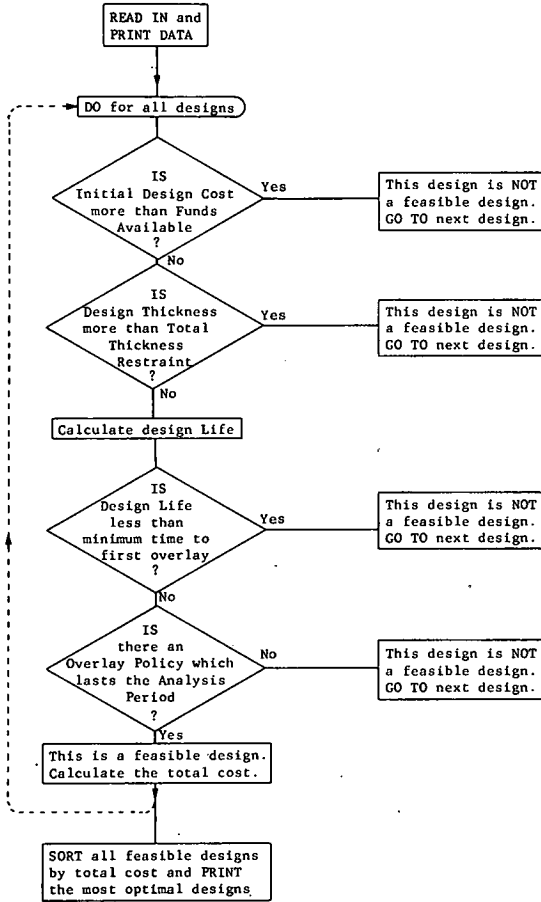
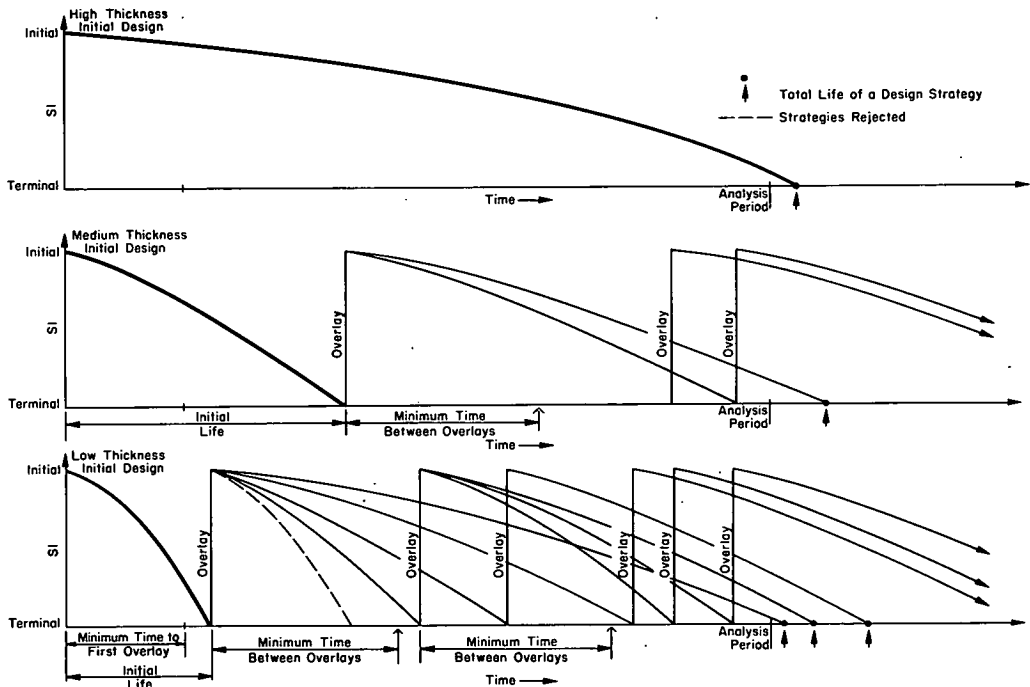


Figure 6. General performance patterns for different initial designs.



Systems Analysis of Example Problems

Nine example design problems were solved by using the flexible pavement system computer program (FPS2) given in Table 1. One is the basic example problem, and the other eight are variations obtained by holding all the variable values, except one, constant. The basic example problem was solved for the inputs shown in Figure 3. These input values are the average values for parameters that will generally be met in practice under average design conditions. Three designs were obtained as output for the basic problem and for each of the other eight problems. The first design for every problem is the optimal design for the input used. Table 1 gives the changes in variables and values and the optimal costs for each problem.

The designs have two or three layers for initial construction and one or two subsequent overlays. Each overlay requires 0.5 in. of a leveling course in addition to the overlay thickness. The number of seal coats varies from one to three. The number of feasible designs considered varies from 1 to 185. The optimal cost of initial construction for these problems varies from \$1.4 to \$3.1 per sq yd of pavement. The optimal design is higher for each of the example problems than for the average problem. This is as expected because each of the variations represents a stricter design condition than the average problem.

FEEDBACK DATA STORAGE AND RETRIEVAL SYSTEM

An important characteristic of an automated pavement management system is that it can continually be evaluated and updated, that is, improved by having needed changes made in the models. This iterative improvement pattern is shown in Figures 8 and 9. An important key to this improvement is the collection, processing, storage, retrieval, and analysis of appropriate data and information about the system.

Too often in the past, pavement design has depended on manual records or general information on plan sheets several years old. Research at the Texas Transportation Institute on this problem has shown that many errors can creep into randomly kept data. The only way these data can be adequately and efficiently processed, stored, retrieved, analyzed, and used to update models is with the computer. Such a feedback-data system must be designed to include a sampling of information on every pavement of interest at each significant time step in the life of the pavement and at each major interval in the life cycle of the pavement (system correction), such as an overlay or a seal coat. A sampling unit for such a data system must be developed so that significant changes in any of the variables in the pavement management models can be adequately assessed. Because approximately 100 variables are being considered, the data storage problem can be quite large.

Design of System

In designing any such data storage system, the pavement engineer tends to make it far too complex and broad because he is "storing all possible combinations of all possible data." This immediately overloads the system with extraneous information and makes it extremely difficult to sort out the valuable data that are available. On the other hand, a simple system designed for easy use may omit the important variables involved and thus provide data that are grossly inadequate for updating models and providing maintenance management and planning and programming information. The obvious answer to this problem is to involve both the pavement design engineer and the information systems designer in a team effort to develop a proper data storage system. This approach has been used by the authors.

Figure 10 shows various kinds of data storage systems that can be used, but only a system in category 4 or 5 can handle the job of pavement management. The concept of a pavement data bank is shown in Figure 11. The general functional format of the pavement feedback-data system used in this project is shown in Figure 12. The major uses of the computer for the supplier and the user of the data are (a) processing input data, (b) updating files with new data, (c) processing output data requests, and (d) retrieving data from the data bank and other data files. The general operating plan of the computer-based data system used for this research project is shown in Figure 13.

Figure 7. Nearly optimal designs for rigid pavement design problem.

SUMMARY OF DESIGNS IN INCREASING ORDER OF TOTAL COST

DESIGN NUMBER	1	2	3	4	5	6
PAVEMENT TYPE	CRC	CRC	CRC	CRC	CRC	CRC
OVERLAY TYPE	CC	AC	AC	AC	CC	AC
REINFORCEMENT TYPE	MESH	MESH	MESH	MESH	MESH	MESH
CONCRETE TYPE	2	2	2	2	2	2
SUBBASE TYPE	2	2	2	2	2	2
SLAB THICKNESS	7.00	7.00	7.00	7.00	7.00	8.00
SUBBASE THICKNESS	6.00	8.00	10.00	12.00	8.00	6.00
OVERLAY THICKNESS 1	5.00	4.50	4.00	3.00	5.00	3.00
OVERLAY THICKNESS 2		2.00	2.00	2.00		2.00
INITIAL LIFE	7.72	8.20	8.64	9.05	8.20	10.88
OVERLAY PERF. LIFE 1	20.74	14.56	15.31	15.21	21.97	16.79
OVERLAY PERF. LIFE 2		23.84	25.02	24.23		25.18
TOTAL PERFORMANCE LIFE	20.74	23.84	25.02	24.23	21.97	25.18
SPACING TRANS. JOINTS	4.00	4.00	4.00	4.00	4.00	4.00
SPACING LONG. JOINTS	12.00	12.00	12.00	12.00	12.00	12.00
COST OF SUBG. PREPARATION	.192	.192	.192	.192	.192	.192
COST OF CONCRETE	2.907	2.907	2.907	2.907	2.907	3.246
COST OF SUBBASE	.585	.752	.919	1.085	.752	.545
COST OF REINFORCEMENT	1.213	1.213	1.213	1.213	1.213	1.346
COST OF JOINTS	.112	.112	.112	.112	.112	.112
COST OF TIE BARS	.020	.020	.020	.020	.020	.023
INITIAL CONST. COST	5.029	5.196	5.363	5.529	5.196	5.544
OVERLAY CONST. COST	1.461	1.387	1.252	1.039	1.427	.953
TRAFFIC DELAY COST	.042	.128	.116	.090	.042	.093
MAINTENANCE COST	.381	.174	.196	.227	.367	.314
SALVAGE RETURNS	-.879	-.887	-.858	-.801	-.879	-.874
SEAL COAT COST	0.000	.142	.080	.079	0.000	.072
TOTAL COST PER SQ YARD	6.034	6.141	6.149	6.149	6.152	6.153

Table 1. Summary of example problems solved by using FPS 2 computer program.

Design Problem	Variable Change	Value Change		Feasible Designs Considered	Optimal Cost (\$/yd ²)	
		Average	Variation		Total	Initial Construction
1	None (average)			185	2.051	1.451
2	Higher swelling clay effect	0.10	0.24	19	3.318	3.134
3	Higher 18-kip axles	4 x 10 ⁶	10 x 10 ⁶	162	2.233	1.604
4	Lower initial serviceability index	4.2	3.8	176	2.136	1.554
5	Higher cost of surface	\$10/yd ³	\$15/yd ³	168	2.342	1.763
6	Lower subgrade strength coefficient	0.25	0.15	36	3.045	2.604
7	Longer time to first overlay	5 years	11 years	81	2.641	2.314
8	Higher average daily traffic	10,000-20,000	25,000-50,000	185	14.942	1.624
9	Fewer funds available for initial construction	\$4/yd ²	\$1.4/yd ²	1	2.092	1.381

Table 2. Schedule of expenditures required for construction and engineering on given highway systems.

Project	Year x ₁	Year x ₂	Year x ₃	Year x ₄	Year x ₅	Year x _i
001	a ₁	b ₁	c ₁	d ₁	e ₁	z ₁
002	a ₂	b ₂	c ₂	d ₂	e ₂	z ₂
003	a ₃	b ₃	c ₃	d ₃	e ₃	z ₃
004	a ₄	b ₄	c ₄	d ₄	e ₄	z ₄
005	a ₅	b ₅	c ₅	d ₅	e ₅	z ₅
006	a ₆	b ₆	c ₆	d ₆	e ₆	z ₆
⋮	⋮	⋮	⋮	⋮	⋮	⋮
n	a _n	b _n	c _n	d _n	e _n	z _n
Total	$\sum_{i=1}^n a_i$	$\sum_{i=1}^n b_i$	$\sum_{i=1}^n c_i$	$\sum_{i=1}^n d_i$	$\sum_{i=1}^n e_i$	$\sum_{i=1}^n z_i$

Note: Expenditures include initial construction, overlays, seal coats, and routine maintenance.

Figure 8. Iterative improvement pattern of pavement design and management system.

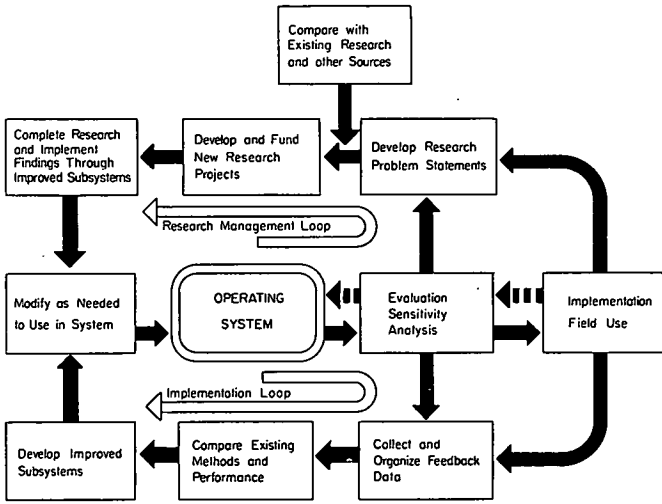


Figure 9. Staged improvements of pavement design and management system.

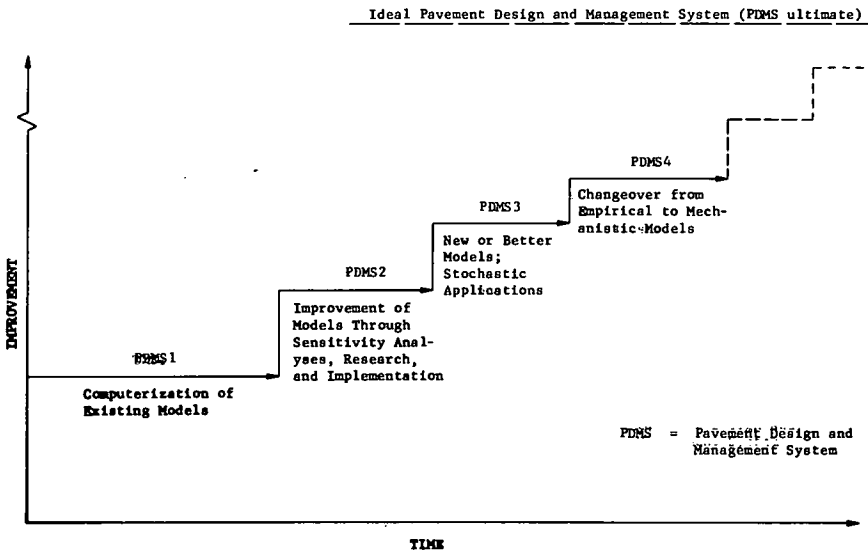


Figure 10. Types of available data storage systems in order of increasing capability.

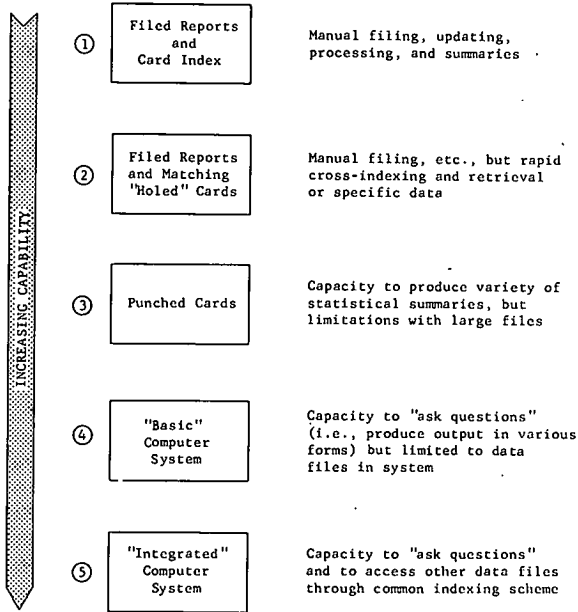


Figure 11. Inputs to pavement data bank.

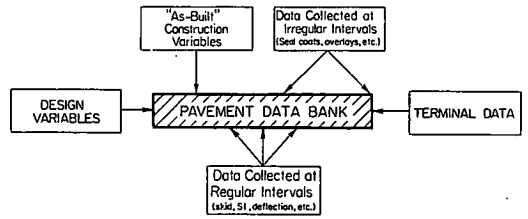


Figure 12. General functional format for pavement feedback-data system.

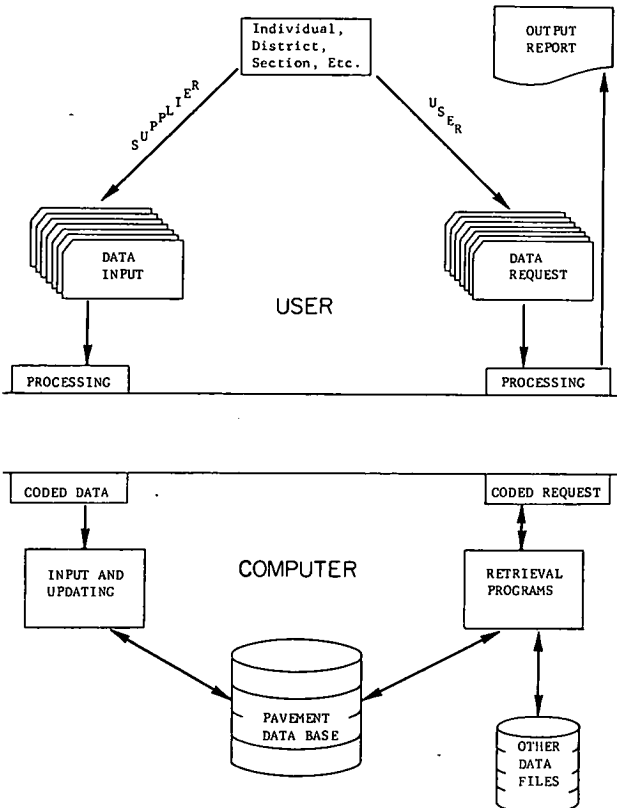


Figure 13. General operating plan of integrated, computer-based, feedback, pavement data system.

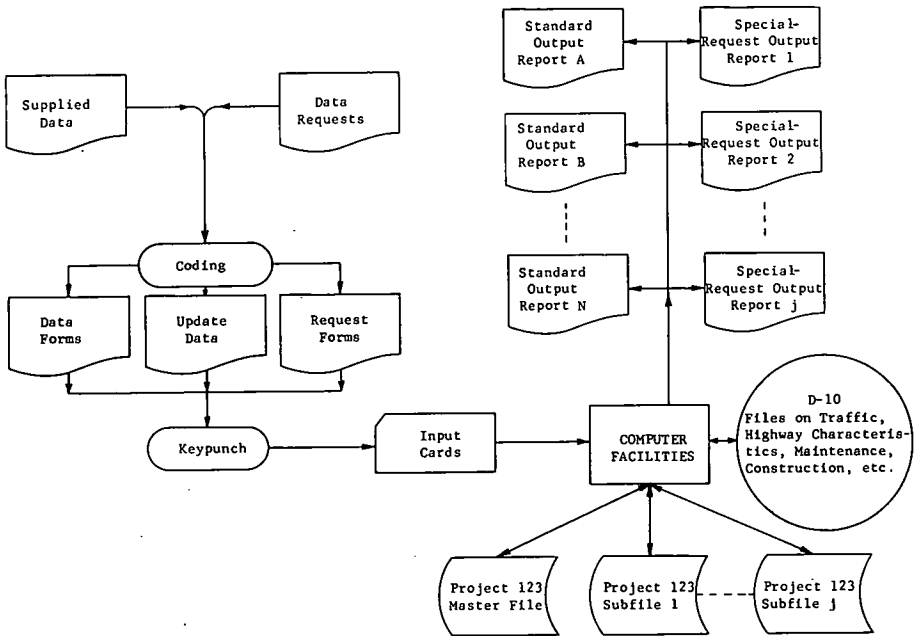


Figure 14. Computer plots of projected and observed histories.

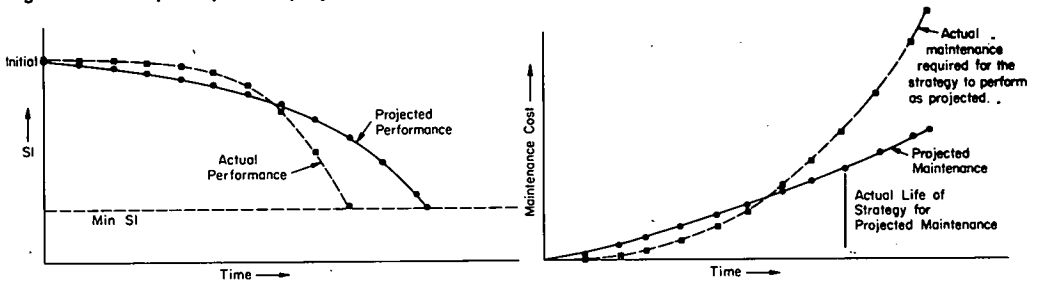
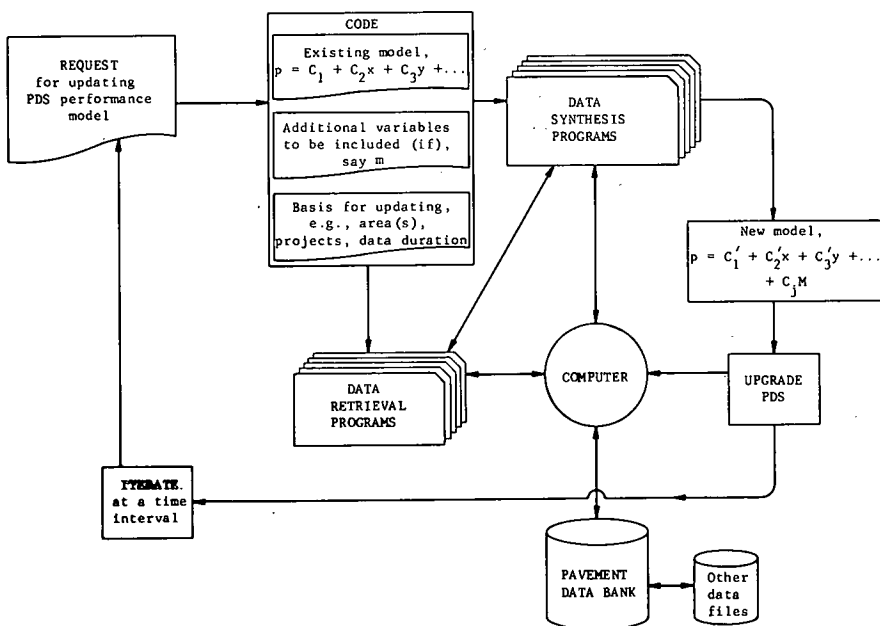


Figure 15. Format for upgrading PDS model using feedback-data system.



Uses of Feedback-Data System

The storage and retrieval of data for the administrator's use constitute one important function of a pavement feedback-data system, but it is not the prime function to a researcher. That function is to provide a useful feedback capability for improving and upgrading the existing pavement design technology. The computer operations necessary to achieve these functions are as follows:

1. Provide input data for the design of new projects;
2. Provide the administrator with data and information on trends applicable to programming and planning;
3. Evaluate the validity of the existing design subsystem models; and
4. Improve PDS models by analyzing the deviations in performance and economic histories.

Figure 14 shows the use of a data system to evaluate models by using computer graphics to plot deviations in predicted histories. Such information is extremely important to a system designer in determining the behavior of his formulated models. Figure 15 shows a functional format for a computer operation that the system designer can use to improve and update PDS subsystem models.

MANAGEMENT AND FINANCIAL PLANNING

Another important characteristic of an automated pavement system is that it allows the projected performance characteristics of the pavement to be used to predict future financial needs and manpower requirements. Too often, expenditures have been based on immediate needs, and there has been little opportunity to establish long-range plans. Thus, there may be no funds for upgrading when a pavement deteriorates below an acceptable riding quality; and it may deteriorate to such an extent that, when funds are available, excessive expenditures are required to regain an acceptable performance level. Also, in some years funds insufficient to meet current needs, and in other years they may be available for a facility that does not yet require upgrading. Thus, optimizing the expenditure of available funds is important, and the ability of an automated pavement management system to do so is highly valuable.

Management

When an engineer using an automated pavement system selects a design, he can refer to a chart, such as the one shown in Figure 16, to find when an overlay and seal coat will be required. The items are laid out on a time scale that gives the highway administrator a schedule of work that will be required for a given section of pavement on a highway system. Based on the actual performance of the pavement, the schedule of work items predicted at the time of initial design can be updated through the use of the feedback-data system previously discussed, as shown by the dashed lines in Figure 16. Thus, the schedule can reflect the most accurate information available at any given time.

Figure 17, an extension of Figure 16, shows the same type of schedule for more than one project. The schedule includes all the sections of a roadway or the total system for a district or for a state, depending on the accounting system being used. The use of such a diagram as that shown in Figure 17 allows the district or state highway engineer to plan the engineering manpower needs for design, construction supervision, and maintenance for a period of 15 or 20 years. If an unusual amount of manpower will be required in a given year, plans to upgrade a given section of road can be made ahead of time to give a more orderly distribution of available manpower and thereby avoid overstaffing during peak periods.

Financial Planning

The engineer can use information such as that shown in Figures 16 and 17 to develop the expenditure requirements for each year of the time period being considered for future planning. An example is given in Table 2, which summarizes the construction cost and the engineering and design cost required through j -years for each section of

Figure 16. Schedule of work for a given project.

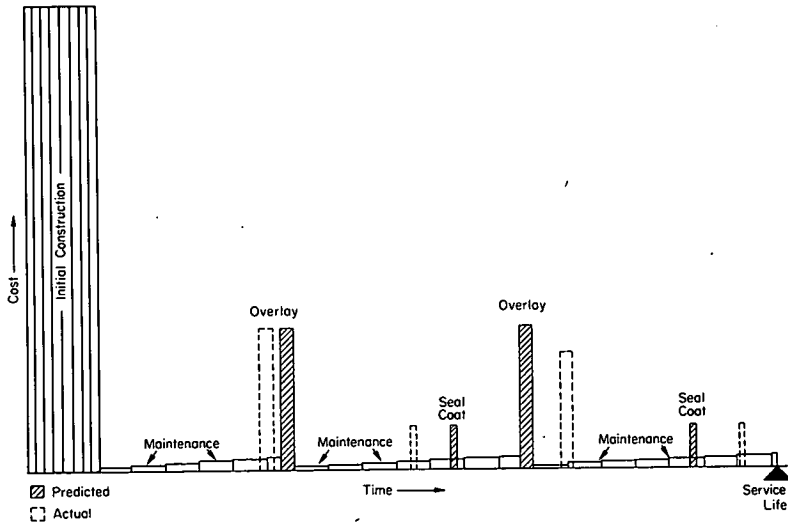
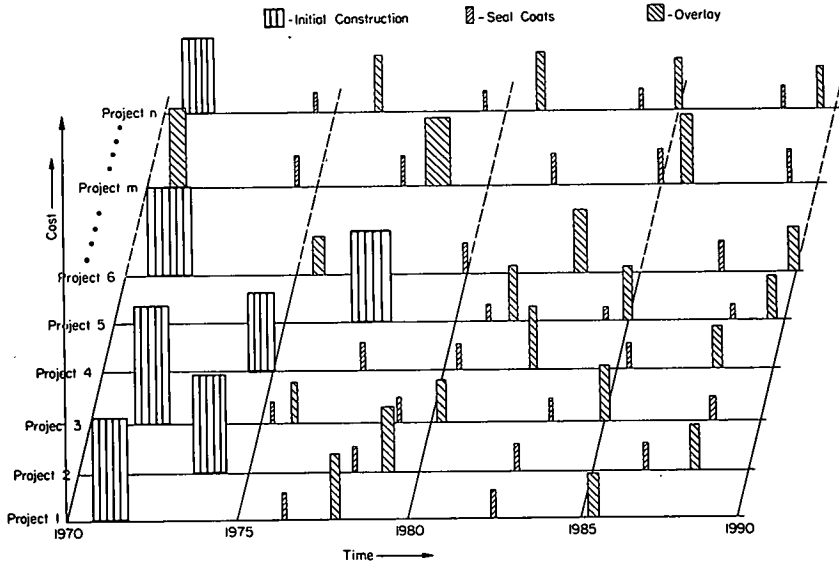


Figure 17. Schedule of work for a highway district or unit.



a project. The costs for a period of time for all the sections can be summed to give the total cost for a given period of time. If the feedback-data system shows differences between the actual performance and the predicted performance, these costs can be changed on a yearly basis. The highest degree of reliability is developed by updating the table each year.

It is apparent that an automated pavement design system is a new tool with which the highway engineer and administrator can reliably predict expenditures required for a highway system for any future period of time. As presented in this paper, a greatly expanded use of available theory and analytical techniques can be achieved by the efficient use of computer speed and storage. Therefore, it is possible to analyze the complex problems of pavement design and management systems. Automation assists in decision-making by selecting favorable alternatives based on various restraints and decision criteria. It helps modify and improve existing design models by storing large amounts of feedback data, and it provides mechanisms for managing future manpower and economic schemes for the administrator.

ACKNOWLEDGMENTS

This investigation was conducted at the Center for Highway Research, University of Texas at Austin. The authors wish to thank the sponsors, the Texas Highway Department and the Federal Highway Administration. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Highway Administration.

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PILOT STUDY OF THE BRIDGE ENGINEERING SUBSYSTEM OF TIES

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In May 1966 a work-study proposal, which outlined the objectives of the pilot study, was submitted to the Bureau of Public Roads by the New York State Department of Transportation. The primary objective was to develop and demonstrate a prototype integrated bridge design subsystem that included computer programs to solve computational problems and generate necessary parameters for plotting. These programs would apply to the major phases of highway bridge design and would be subject to decisions made by the engineer.

Work under this project was begun in January 1967 with a staff of engineers from the Bridge Design and Construction Subdivision and systems analysts and programmers assigned to the Bureau of Electronic Data Processing.

To accomplish the desired results within a reasonable length of time required that the scope of the pilot study be limited as follows:

1. Bridge over one or two roadways;
2. A maximum of 4 spans;
3. A maximum of 10 beams in cross section;
4. Bridge of constant width and tangent or circular curve alignment; and
5. Simple spans (composite rolled beams or welded plate girders).

From the standpoint of the TIES project, development of a prototype bridge design subsystem serves two major purposes: (a) It results in a workable system that can be expanded to accomplish the bridge design aims of TIES, and (b) it serves as a model for accomplishing the necessary functions in other subsystem areas and, ultimately, for developing the overall TIE system.

It was decided that a method should be adopted that would facilitate the accomplishment of the overall research goals and yet allow the earliest possible use of the programs developed. In effect, this plan allowed the results of the research to be implemented concurrently with its development.

Based on the premise that each independent program would be a unit in an integrated system, the following guidelines for the study were established:

1. Develop computer programs on an individual basis for each program area, condensing similar processes into a single program wherever possible;
2. Integrate these programs into a workable system that will automatically execute all phases of the design but, to avoid duplication, retain the option for independent program execution; and
3. Expand the system to include plot programs wherever practical.

As an initial step in the research process, letters requesting material for the project were sent to 17 highway departments throughout the country. Replies were received from all agencies contacted, and many agencies submitted source decks and program documentations.

These materials were reviewed by the engineering personnel assigned to the project to ascertain which of the many programs submitted would be most effective.

Recommendations concerning these programs were approved by the Bureau of Public Roads. Also, in line with the aforementioned guidelines, it was agreed that the program areas originally envisioned should be condensed into eight computer programs as follows:

<u>Function</u>	<u>Program</u>
Control geometry	B0500
Framing plan	B0600
Reinforced concrete slab design	B0800
Beam and girder design	B1500
Bridge bearing design	B3500
Abutment and retaining wall design	B5000
Pier design	B6000
Bridge quantities	B8500

The two geometry programs, one to produce control dimensions for a bridge and the other to produce a satisfactory framing plan, were developed by modifying and supplementing the recommended available programs.

Because programs were not available to serve this function, the reinforced concrete slab design program originated with the study. We have also developed a program that will detail slab reinforcement for straight bridges with the main reinforcement parallel or normal to the stringers. The beam and girder design program is based on logic contained in two available programs originally recommended but has been completely rewritten in its combined form. It also processes many designs in an attempt to select the most economical section within the specified depth range. A program for the design of bridge bearings was not available but was needed to prepare a complete design. This program was initiated in the project. In addition to its design function, this program also acts as a collector and provides the necessary input information for the substructure design programs.

The abutment and retaining wall design program is based on logic contained in three available programs originally recommended. Major modifications have been made in the combined program. The program will not design either abutments or retaining walls on spread footings or on piles. Rather, it processes a series of designs in an attempt to select the most economical section based on concrete volume and number of piles, if applicable.

The recommended pier design program has been modified to design the required steel reinforcement in the pier beam and columns. Logic has been added to design individual or multiple-column, spread or pile-supported footings. Subroutines have been added to the program to detail the reinforcing steel in the beam, columns, and footings. The originally proposed bridge quantities program will not be a part of the pilot study but will be developed in the future as time permits. It will be a collector type of program that will accumulate and combine quantities determined in other design or plot programs.

We have tried to design all of these programs so that they may be executed both within the framework of the bridge engineering subsystem for TIES and on a stand-alone basis. In this way, it is hoped that users not yet possessing third-generation equipment may still be able to utilize the results of this research.

We have also written programs for the plotting phases of the pilot study. Subjects included in these plot programs include the following: general plan of bridge, framing plan, transverse section, beam and girder schedules, abutment details, pier details, and slab bar plan for straight bridges.

In addition to those various design and plot programs, we have also developed a master control program that allows the execution of the various programs within the system in a pre-established order. By using a system of interim disk storage, the control program will allow information to be passed from a given program to any other program in the system.

The first phase of the master control program edits the input data from cards and sets up the intermediate data file for a particular bridge design. The data for all programs can be input in random order. Tests are made on each record immediately after it is entered to determine the proper program location for the record, and a sequence check ensures the proper placing of the record in its program area. The data are arranged in blocks and in the same form as the input forms for individual execution so that additional data from other programs may be entered to update the file. Data

from a project master file can be entered by the same process if the contents and order of the master file are pre-established.

The second phase of the master control program determines which programs are to be used and in what order they are to be run, initiates the execution, and automatically keeps track of the order of program execution. This second phase is entered from the first phase and from all the individual programs involved during any system execution.

The following is a description of the design of a bridge illustrating the use of the various programs in the bridge engineering subsystem (BEST). The bridge selected was designed in 1967 before any of the BEST development work, which allows a valid comparison to be made between the original design and a system design.

The bridge is a two-span crossing of two proposed roadways. The abutments have been placed 30 ft from the edge of the pavement, the minimum clearance under the Highway Safety Program. The structure has solid abutments on spread footings and a two-column pier on a combined spread footing. The superstructure is composed of steel-plate girders spaced 8 ft on centers. The bridge carries a straight roadway and is placed at the crest of a vertical curve. The structure was built near Syracuse, New York.

The first step in the system design is the preparation of the input to the control geometry program. The input consists of horizontal and vertical alignment and cross-sectional information about the upper and lower roads. Ultimately, it is planned that this information will be passed to the bridge design subsystem by the roadway design subsystem of TIES being developed by the Texas Highway Department.

In addition, horizontal and vertical clearances and design criteria such as footing elevations and steel type are input by the engineer. By varying these input criteria, the engineer is able to produce a variety of designs that he may use as a basis for comparative estimates.

The printed output from this program consists of the locations and azimuth of the substructure, placed in accordance with the input clearances and design criteria, and the depth available for the steel stringers to be included in the superstructure.

The program also writes information for subsequent programs on the subsystem working file, where it may be updated by other programs as additional information is required by them. The applicable information on the working file is written on prescribed locations and in the format as described in the format statements included in the appropriate read subroutines of the subsequent programs. Instructions are included in the beginning of each program to print or tabulate the contents of the program's input file. If a complete design is processed, some interim decisions must be made based on information generated since the beginning of the run. The engineer has ultimate responsibility for the design and should have complete control over it. In this program he can override any of the interim decisions by updating the input files and rerunning the programs affected by the change.

The structure laid out by the control geometry program is a two-span bridge. The dimensions in the plot, however, show that the system-designed bridge is 22 ft longer than the original design. The program determined that a span with an additional 11 ft could be used effectively without encroaching on the vertical clearance.

The next step in the system design process is the determination of the framing plan layout. These items are similar to the geometry program data items and consist of horizontal and vertical alignment and cross-sectional information about the bridge and the stations and azimuths of the piers and abutments. All of this information is obtained from the input disk file prepared by the control geometry program. The output from this program consists of stations for the beam end points, offset distances measured from the station line to the beam end points, finished slab elevations of the beam length, and azimuth or alignment of each beam. The plot of the framing plan was prepared by another process program in the automated design system. The framing is similar to the original design except for the span lengths. An additional bay of cross frames (determined by the computer to be needed to accommodate the longer spans) was added.

Next, we proceed to the beam or girder design. Input is read from the subsystem working file. This information consists of bridge dimensions, sidewalk width, curb

height, number of lanes of traffic and number of beams, allowable steel depth, span length, beam spacing, and an overhang dimension for fascia beams. The program initially designs an economical beam or girder for the longest span in the bridge. It establishes this depth as the minimum depth for fascia beams to provide a pleasing appearance, and then it proceeds to design each individual beam or girder. Printed output from this program consists of a detailed description of all the components of each beam or girder, together with stresses, reactions, and deflections. Again, information is written on the working file for use by subsequent programs. The beam and girder tabulation and the transverse section plot programs then draw on information from the input disk files to make the necessary computations to prepare the appropriate plots.

The next step in the process is the deck slab design. Information is read off the subsystem working file and consists of the stringer spacing, flange width, and assumed slab thickness. The program designs the transverse reinforcement in the interior spans and the fascia overhangs and the longitudinal distribution steel. Printed output consists of the size and spacing of the reinforcing bars. The deck slab plot program then reads information from the file and prints out a detailed reinforcing bar list for the slab and makes the necessary computations for the deck slab plot.

The bearing design program retrieves the necessary information, such as stringer reactions and span lengths, from the working file and designs the bearings for each beam. Printed output consists of a detailed description of the component parts of each bearing and beam seat elevations that are based on the dimensions of the previously designed components of the superstructure. By using parameters determined in this and the previous programs, the program arranges appropriate data for the substructure design and plot programs.

The abutment and retaining wall design program uses the data from the working file and designs two abutments and up to four wing walls depending on the differences in height. Printed output from this program consists of complete cross-sectional dimensions, necessary reinforcement, and piles, if required, for each of these structures. It then prepares data for the abutment plot program and places those data on the working file. The abutment plot program, using those data from the working file, performs the necessary computations to prepare a plot of the abutment plan, elevation, and appropriate cross sections. Because of the increase in spans previously mentioned, the abutments were not nearly as high as those in the original design. The footings of the abutments were approximately the same length, but, because of the lower height of the system design, the width of the footings was approximately 4 ft narrower. The lengths of the wing walls were also about 7 ft smaller, and the height of the abutment was 4 ft lower.

The pier design program uses information placed in the working file by the bearing design program to analyze the pier based on assumed concrete dimensions of cap beam and column and to design the foundations and all necessary reinforcement. Printed output from this program consists of a detailed description of the reinforcement and, if necessary, the pile pattern for the foundations. It next completes the input data for the pier plot program, which in turn performs the necessary computations to prepare the plot of the pier plan, elevation, and sections. As might be expected, the pier is similar to that in the original design. Differences are due primarily to the additional length of the supported spans.

The time for this layout, analysis, and design was 35 minutes. Plots were processed off-line on a Calcomp plotter using magnetic tape. Plotter time for the drawings was approximately 3 hours. The cost of this complete design was approximately \$120 based on estimated computer and plotter usage.

Comparison of the BEST design with the original design indicates one major difference. The design using BEST resulted in spans approximately 11 ft longer than those used in the original design, with a resultant reduction in abutment height.

Although the original design satisfied the minimum lateral clearance required under the Highway Safety Program, the system design has the somewhat intangible advantage of providing an additional 10 ft of lateral clearance. At the same time, a comparative estimate using actual bid prices for the construction of this structure indicates that it would have achieved this advantage at a lower cost than the original design.

This structure was built, under contract, at a cost of approximately \$212,000. The increased superstructure costs of approximately \$20,000 from the system design would have been more than offset by the reduction of abutment and approach costs amounting to approximately \$45,000. The net cost reduction of \$25,000 would result in a cost of \$187,000 for the structure designed by using the system.

This random comparison, as well as the many others we have made during the development stage, has indicated great potential advantages with the systems approach to bridge design. Although this system was developed as a prototype and is, therefore, limited in scope, we feel that it would be of advantage to extend this approach to include a much greater percentage of our work load. Including other types of construction, such as continuous steel and prestressed concrete members, would make the systems approach much more versatile and could provide additional economic benefits in permitting comparative designs to be quickly and easily made.

SYSTEMS FOR BID ANALYSIS, GUARDRAIL LOCATIONS, CONSTRUCTION SCHEDULING, AND ESTIMATING EARTHWORK QUANTITIES

W. A. Wilson, Jr., North Carolina State Highway Commission

BID ANALYSIS

For a number of years, in North Carolina, we have used a series of computer programs to expedite the handling of bid-letting data and associated items. We are now in the process of adding another major program to the series that will greatly expand the current bid facilities and, at the same time, reduce much of the manual work. The new bid series will use the engineer's estimated unit bid prices to assemble the bid items into the proposals, write the item sheets, and list all of the breakdowns for state and federal highway projects. After the letting, all of the listings are repeated and the low bidder's prices are used. The new bid system in conjunction with a system such as a magnetic tape selectric typewriter for the preparation of project special provisions provides our plans and proposal section with a system that is as automated as possible at the present time.

The main purpose in adopting a new bid system was to ease some of the work load caused by the presence of multiple projects within one contract and to facilitate the classification of quantities for each in the proposal. It also allows us to separately prepare sets of items such as roadway, signing, landscaping, culverts, and bridges and to use the computer to combine these sets into one proposal. In the past, the computation of these breakdown estimates has been an extremely time-consuming task for the engineer. For example, one structure proposal had 17 bridges and 2 federal-aid numbers, which required the assembling of 20 different estimates. With the new bid system, this proposal would require only about a minute on the computer. On another occasion, a group of eight bridges and a section of roadway were to be let in two separate contracts. Shortly before letting day, the roadway and structures were combined into one contract, which caused a tremendous amount of work. With the new system, there would have been no difficulty in making the change.

Once the engineer has completed the computation of the quantities and items that make up each project or breakdown, he must prepare input data forms for those projects. We have approximately 500 standard item descriptions that account for about 90 percent of all bid items used except for right-of-way and landscape items. These standard items are stored and may be recalled by a three-digit code. Nonstandard or special items must be completely written out on the input form. The items on the input form are also given a line or ordinal number. These numbers are usually given in increments of 2 so that additional items may be added or deleted without disturbing the remaining numbers. When a computer output is obtained, these lines are renumbered in the standard number sequence, i.e., 1, 2, 3, 4. The maximum number of items allowed in one proposal is 400, and we have had as many as 370. The maximum number of breakdowns that are allowed for any proposal is 30.

In each item description, there is also a code letter to indicate the group type to which an item belongs, e.g., grading, paving, culverts, or bridges. From this a cost analysis of each group can be made.

After the input forms are processed, the breakdown quantities are totaled in the computer for each proposal, and a list with the total quantities is printed for the use of the plans and proposal section in assigning unit prices for the various items in the

proposal. These unit prices are returned to the computer section, and three additional lists are prepared.

The first list contains total quantities for the proposal, from which group costs are obtained. The second list contains each separate breakdown, from which cost per foot for roadways, cost per square foot for bridges, and cost per cubic yard of waterway for culverts are obtained. The third list is for the use of the Federal Highway Administration and is arranged according to its code.

Item sheets may be printed at any time to be photocopied and included in the proposal; they are usually printed on colored paper to simplify assembling the proposal and to facilitate their use.

When alternates are present in a proposal, there are two methods of selecting materials, both of which depend on whether the material choice causes any change in the number of items concerned or the quantities or both.

If the items and quantities are basically the same, the bidder may specify an X, in the space provided, for the material he wishes to use for the next predetermined number of items.

Where the material choice affects the quantities, for example, in brick end walls or concrete end walls, there are several items on each side of an alternate. Contractors may bid on either side of the alternate without specifying which side or may even bid on both sides, in which case the program selects the most economical items and discards the others.

Bidding cards are made up for the exact number of bidders on letting day. These prepunched cards contain the computer proposal number, item number, and lump sum or total in the unit price bid columns where appropriate. Three item bids are entered on each card.

The data processing section normally receives the proposals about Tuesday noon and usually completes the processing about 10:00 a.m., Wednesday. The letting output includes (a) listings of all bidders, three to a page; (b) the engineer's estimate and low bidder printed side by side; and (c) the letting summary showing the three low bidders and the date of availability and date of completion for the project.

After the letting, all engineering breakdowns for the different work orders in the projects are recomputed, and the actual unit bid prices received from the low bidders are used.

For the computation of average unit bid prices, a tape is written of the low bidders' prices, and for each bid item the item description number, quantity, and amount are later punched into the cards along with header information. The header data include the letting date (year and month), the project number, the route number, the location (county, division, and area), and the roadway standard (Interstate, primary, secondary, and rural). The low bid costs are checked out each month and accumulated.

Every 6 months, we print the header details with the total costs, followed by the quantity and average unit bid for each standard item. This is done first for the whole state, then for each of the 14 divisions. For each year, we print and distribute books containing the average unit bids for each standard item.

On demand, we can make a choice of averages by date, project number, route, location, or highway standard. This has been very useful in making Interstate highway estimates.

GUARDRAIL LOCATIONS

We have used the computer to determine guardrail locations in preliminary design for several years. Our program bases guardrail warrants entirely on embankment geometry as outlined in the National Cooperative Highway Research Program Report 54.

Our guardrail program is a subsystem of the earthwork system. The guardrail locations, along with the slope required to eliminate the guardrail, are returned each time the earthwork system is run and the guardrail is requested. This enables the design engineer to determine whether it is more economical to flatten fill slopes to eliminate the need for guardrail or to place the guardrail.

This study can be conducted in a variety of ways; the following approach can be used both by installations that have a plotter and by those that do not.

Figure 1. Construction limit plot with clearing-seeding-guardrail.

SCALE 1 INCH = 50 FEET
 I INDICATES THE RIGHT OF WAY LINE
 * INDICATES THE SLOPE STAKE LIMIT
 (NOT PRINTED WHEN ON THE R/W LINE)
 * BESIDE THE CENTERLINE INDICATES
 THAT GUARD RAIL IS REQUIRED
 SLOPE NO-GR IS THE SLOPE REQUIRED TO
 ELIMINATE GUARD RAIL
 CLEARING AND SEEDING AREAS ARE IN
 SQUARE FEET UNLESS OTHERWISE NOTED
 STEEP SEEDING (SLOPE STEEPER THAN 1.5 TO 1)
 CLEAR TO THE CONSTRUCTION LIMITS

SLOPE	SLOPE	CLEARING	SEEDING	R/W		C STATION	C	R/W	SEEDING	CLEARING	SLOPE	SLOPE	
LEFT	NO-GR	LEFT	LEFT	LT		LINE BK L		RT	RIGHT	RIGHT	NO-GR	RIGHT	
3.00C				80	I	11+00	I					2.00C	
3.00C			4059.0		I	12+00	I			3072.5		2.00C	
3.00C		2945	5909.0		I	13+00	I			2804.5	3490	2.00C	
3.00C		6790	6320.5		I	14+00	I			2603.5	3275	2.00C	
3.00C		6175	5672.5		I	15+00	I			2592.0	3270	2.00C	
3.00C		4965	4391.5		I	16+00	I			2648.0	3320	2.00C	
3.00C		4410	3806.0		I	17+00	I			2883.0	3525	2.00C	
3.00C		5390	4833.5		I	18+00	I			3743.5	4285	2.00C	
3.00C		5340	4770.5		I	19+00	I			4850.5	5270	2.00C	
3.00C		4060	3426.5		I	20+00	I			5644.5	5990	2.00C	
3.00C		2745	3078.5		I	21+00	I			5532.5	4492	2.00C	
3.00C			3474.0		I	22+00	I			3989.5		2.00C	
3.00F			3338.5		I	23+00	I			2505.0		4.00F	
3.00F			3332.0		I	24+00	I			3294.5		1.50C	
4.00C			3721.0		I	25+00	I			5085.0		1.50C	
4.00C			3803.5		I	26+00	I			6067.5		1.50C	
4.00C			3030.0		I	27+00	I			5725.0		1.50C	
2.00F	2.44F		3759.0		I	28+00	I*			3763.5		2.00F	
2.00F	2.46F		5223.5		I	29+00	I*			3010.0	2.06F	2.00F	
2.00F	2.39F		5145.0		I	30+00	I*			3893.5	2.18F	2.00F	
2.00F	2.25F		4815.0		I	31+00	I*			4195.0	2.20F	2.00F	
2.00F	2.10F		4234.0		I	32+00	I			4105.5		2.00F	
2.00F	2.58F		4776.5		I	33+00	I			3602.5		2.00F	
2.00F	2.58F		5693.0		I	34+00	I			3188.5		2.00F	
2.00F	2.71F		6084.5		I	35+00	I*			4127.5	2.42F	2.00F	
2.00F	2.69F		6420.0		I	36+00	I*			5245.5	2.51F	2.00F	
2.00F	2.73F		6475.5		I	37+00	I			5368.5		2.00F	
2.00F	2.19F		5424.5		I	38+00	I			3636.0		2.00F	
2.00F	2.14F		4150.0		I	39+00	I			2354.0		2.00F	
2.00F	2.21F		4851.0	1001	I	40+00	I			2846.5		1.50C	
1.50C		5235	5113.0		I	41+00	I			5157.5	5390	1.50C	
1.50C		6480	6462.0		I	42+00	I			8141.5	7875	1.50C	
1.50C		8360	8722.5		I	43+00	I			7988.5	7745	1.50C	
1.50C		8285	8632.0		I	44+00	I			6582.0	6755	1.50C	
1.50C		7300	7444.5		I	45+00	I			5238.5	5465	1.50C	
1.50C			6924.5		I	46+00	I			4842.0		1.50C	
1.50C			6861.5		I	47+00	I*			4643.5	2.41F	1.50C	
2.00F	2.12F		5332.5		I	48+00	I*			5172.5	2.66F	2.00F	
2.00F	2.12F		204.2		I	48+05	I*			317.1	2.66F	2.00F	

BEG BR													

END BR													

2.00F	2.44F				I	50+25	I*					2.52F	2.00F
2.00F	2.44F		3976.5		I	51+00	I*			3884.3		2.27F	2.00F
2.00F	2.41F		5067.0		I	52+00	I*			4474.5		2.14F	2.00F
2.00F	2.31F		4474.5		I	53+00	I*			4038.5		2.07F	2.00F
2.00F	2.11F		3815.0		I	54+00	I*			3759.0		2.05F	2.00F
2.00F			3736.5		I	55+00	I			3535.5			2.00F
2.00F			3580.0		I	56+00	I			3233.5			2.00F
2.00F			3144.0		I	57+00	I			3077.0			2.00F
2.00F			3010.0		I	58+00	I			3122.0			2.00F
1.50C			3054.0		I	59+00	I			3133.0			2.00F
1.50C			4779.0		I	60+00	I			2872.5			2.00F
1.50C			5852.0		I	61+00	I			1727.5			4.00F
1.50C			7087.0		I	62+00	I			3691.5			3.00C
1.50C			9800.5		I	63+00	I			5942.5			3.00C
1.50C			10377.5		I	64+00	I			5672.0			3.00C
1.50C			8718.5		I	65+00	I			5482.5			3.00C
1.50C			9052.0		I	66+00	I			4779.0			3.00C
1.50C			9232.5		I	67+00	I			3980.0			3.00C

LEFT CLEARING			LEFT SEEDING			RIGHT SEEDING			RIGHT CLEARING				
TOTAL	78480	288471.2	TOTAL	32052.4	TOTAL SQ YDS	TOTAL	226925.4	70107	TOTAL	25213.9	1638	OUTSIDE R/W	
OUTSIDE R/W	0	0.0	SQ YDS STEEP CUT	0.0	SQ YDS STEEP CUT	0.0	1.572	ACRES IN R/W	0.0	0.376	ACRES OUT R/W		
ACRES OUT R/W	0.000	0.0	SQ YDS STEEP FILL	0.0	SQ YDS STEEP FILL	0.0			0.0				

A guardrail and construction limit plot are prepared for the roadway section (Fig. 1). The slopes used are printed on the left and right sides of the sheet. In areas where guardrail is warranted, the slope required to eliminate the need for guardrail is printed next to the slope used. The clearing and seeding areas are the next items printed and then the distance from the centerline of lane to the right-of-way. The right-of-way line is indicated by a row of I's and the slope stake line by a series of dots. This gives the design engineer an idea of how much he may flatten slopes without exceeding the right-of-way. At guardrail locations, a series of asterisks representing the lane centerline is printed next to the row of I's. The station value at which the cross sections are taken is the final item on the listing.

This list was generated on a printer; if a plotter were used, a better representation of the right-of-way line and slope stake limits could be obtained. The total areas of clearing inside and outside the right-of-way are printed at the bottom of the list along with the areas for erosion control.

CONSTRUCTION SCHEDULING

The use of the critical path method for the scheduling of highway construction work has been tried several times in North Carolina. The results have not been satisfactory. The major difficulty in preparing a critical path before a contract is let is that the exact resources of the successful bidder are not known; the critical path is, of course, somewhat dependent on these resources. However, the method does help the engineer in planning work over which he has control. The method requires that the engineers familiar with construction requirements, bridge design, and roadway design get together and build the highway on paper. This eliminates some of the problems that occur during the actual construction of the project.

The difficulties in preparing a critical path may possibly be avoided by preparing a tentative critical path based on past experience with similar projects. Once the contract has been let, this tentative critical path could be changed to conform to the capabilities of the contractor. Once these changes are made, a final critical path could be prepared for use in the construction of the project.

ESTIMATING EARTHWORK QUANTITIES

The use of computers to compute final earthwork quantities has simplified the work of resident engineers.

We are set up to handle cross sections, which may be taken in several ways. The fastest method is the use of photogrammetric processes. In this system, the project area is flown and photographed in stretches of approximately 2 miles as it is cleared and grubbed. Vertical and horizontal controls are, of course, established at the time of photographing, and the cross sections prepared on a stereo compiler are closely edited for conformance to these controls. When grading is completed, the project area is photographed again; these photographs provide information for the final, or as-graded, cross sections. After these sections are edited to ensure conformity with the vertical and horizontal controls, they are merged with the original sections and the volumes are computed. When a section is paved before being photographed, the resident engineer must supply template sections that cover the area from ditch point to ditch point; the remainder of the section is supplied by the photogrammetric section.

On small jobs where the cost of flying is not justified by the savings in time, cross sections may be taken by field methods. These field sections also serve as input to the final estimate volume program. The program is flexible enough to handle a mixture of the two types of sections if necessary.

The output of the program consists of excavation quantities, and embankment quantities and borrow pit calculations are available if desired. On sections that are taken by photogrammetric processes, or sections that are taken to actual elevations, the centerline subgrade elevation is given. The left and right tie point distances from the centerline are also given along with the depth of cut or height of fill at the tie point.

PART III

ADMINISTRATIVE MANAGEMENT SYSTEMS

ADMINISTRATIVE MANAGEMENT INFORMATION SYSTEMS

Theodore E. Stephenson, Jr., Wisconsin Department of Transportation

I have arranged my discussion of administrative management information systems to fit problem-solving processes of (a) gathering the facts, (b) defining the problem, (c) developing alternatives, and (d) making recommendations.

GATHERING THE FACTS

The purpose of an information system is to provide information needed by the user for the conduct of his business. The administrative management information system is an information system that provides the manager with information that he needs to make decisions concerning the internal operations of his organization. Administrative activities are those activities required to operate an organization. Administrative personnel consists of a chief executive officer and all other personnel who supervises one or more employees. The management process consists of four basic steps: (a) planning, (b) organizing, (c) directing, and (d) controlling.

This paper deals with those activities that relate to an organization's internal performance and production capabilities. These activities are (a) personnel and payroll, (b) budgeting and accounting, and (c) data processing and other centralized or standard services such as purchasing. All of these activities can be automated, but before automation is considered, management must make sure that its present administrative information system is reasonably clean and effective.

The term information system is of recent origin, although the news media have long collected information for popular dissemination. Business and government have processed quantitative data for inventory and production control, billing, and accounts receivable, and innumerable other applications. Only recently, however, has it been possible to pull together both quantitative and nonnumeric data into a single integrated system serving many applications at one time. This is the result of two trends: increasing use of computers and increasing need for computerization of documentary data. These trends result from the limitations of precomputer data processing.

Data processing by hand or by electric accounting machine can solve small independent problems involving only numeric data. The problems must be small because the processor has a small memory. Any data common to two problems can only be stored in the processor's memory at the expense of active storage for each problem. The problems must be numeric because the processor functions are limited to arithmetic operations. These problems are essentially all transaction-oriented; that is, the same set of operations is used on each transaction in the input stream.

Given this capability, uses were developed that made excellent economic sense. Work such as preparation of payrolls, cost accounting, and invoicing can be done one transaction at a time with practically no reference to a backup file. Thus, the data processing industry thrived by selling unit record equipment to the chief financial officer.

The unit record itself strongly influenced the type of data processing done on accounting machines and early computers. The unit record, typically an 80-column card, contains fixed-length fields in predetermined card columns. Space can be conserved by using code numbers rather than written information. Consequently, the computer era opened in an environment in which all information was represented as numeric codes in fixed positions within a fixed length unit record. For several years, computer applications were just bigger and better accounting machine applications. Then, as

computer storage costs decreased, designers began to use storage as a bridge between applications within a functional area. Within the personnel area, for instance, all employee data were gathered into a single file that was used for payroll, home address listings, organization directories, and vacation records. Historical data, conversion tables, cross-reference tables, and results of completed programs were stored for later use by other programs. The data were still mostly numeric and the fields were of fixed length, but the integrated systems began to include records of varying length. Processing was still transaction-oriented in that each transaction usually affected only one record in the file.

Although this trend modified the character of data processing, the information explosion was generating a requirement for nonnumeric processing of library books and catalogs, legislation, and foreign languages. The key feature of nonnumeric processing was the dominance of alphabetic data—ordinary words and phrases. A simple library system would provide a list of documents that would satisfy the request of a user.

The users of nonnumeric systems had requirements for very long alphanumeric records. Some of the records were formatted as were unit records, but the fields were not all of predetermined length. As a means for coping with this, the formatted file concept was developed. It had the ability to handle records of variable length by referring to a data definition that described the permissible record contents, context, and internal structure.

The early practitioners of nonnumeric processing were the only ones to describe their work as information systems. They soon recognized, however, that the information system was, in fact, a more general case of integrated data processing. This recognition relaxed the constraints on both data structure and language that had been taken for granted. It also gave promise of applying computers to areas of business planning, operation, and management that had been ignored because they were not easily quantifiable. As a result, computers and information systems are now understood well enough to be utilized in the management process effectively. We must now search out administrative activities that can benefit from use of these tools.

Within the scope of fact gathering, we must define nontechnical limitations within which administration activities can be automated. We must understand the organizational or governmental agency. We must understand that most highway agencies operate within, or potentially within, a department of transportation, which in turn operates within a state government that may have a statewide department of administration. The fact is that most state agencies operate within a hierarchy of administrative services. We must find out who performs these services so that we can get needed information for the decision-making process.

Assume the following hypothetical set of jurisdictional facts: There are statewide payroll and accounting systems but no statewide or agency automated personnel system. Each agency is responsible for preparing its own budget and its supporting facts. There are separate statewide and agency computer services. In this example, if we want automated personnel or budget information, we must develop the systems ourselves. If this is desired, we would use our own computer to support these automated-information applications. We would have to cooperate with, and solicit from, a higher level organization to get the information our agency needs for other administrative decision-making. In general, any agency that has the data-gathering responsibility for a small number of information categories (regardless of the number of data elements in the categories) is likely to find it easier to instrument an information system than will the agency responsible for many interacting information categories.

An information system uses a centralized data base for all its tasks. The data in the data base must be valid and current. The procedure for ensuring this and for guaranteeing that only one current copy of each file exists must be carefully planned and executed. This is a difficult and time-consuming task that should not be duplicated. It is a good rule to let the high-level organization be responsible for maintaining the data base. What is needed are information reports that give everybody a common base from which to make decisions.

The task of gathering the facts for designing an information system for an organization can be approached in one of three ways:

1. Identify, define, and lay out the classical administrative and management functions that should apply based on "textbook" knowledge;
2. Study the functions performed in the organization and automate them; or
3. Study the information flow of the organization and build a system that brings the basic information together and makes it accessible to all functional groups.

In general, the third approach is the most fruitful. The first method is weak because it ignores the "personality" of the organization; it is impossible to mold the organization to fit the textbook, and it is generally impractical to fit the generalizations of the textbook to the specifics of the business. The second method is practical but weak because it tends simply to speed up the way the business has operated. If the business is not well suited to data processing automation, the technique will fail. This approach can usually be justified if the work load outstrips the capability of manual methods. However, the system is generally unsuccessful if it merely increases the fixed cost of data processing without actually improving the process. The third method, on the other hand, takes advantage of the fact that the business organization is the creation of the information that flows through it.

What information is needed to perform the management function? First, we must identify the information flow. It is here that value-judgment decisions must be made by administrative staffs. This step is best shown by listing a few questions that management may ask. These lists identify how management will use the information for analysis prior to making a value judgment. For example, the following series of questions may be important.

1. How many dollars of bonding revenues are planned for expenditure in the next year?
2. How many dollars of the last bond issue have we spent?
3. How many dollars must be offered for the next bond issuance?

By using answers to such questions, the systems analysts can design reports that identify the necessary data elements, select the source of data, and define the necessary information flow. The design includes a set of specifications for the information system that describes exactly how the system will be built to meet the objectives established for it by management. The specification is a document that includes a flow chart of the information paths in the organization, a picture of the data bases on which the system depends, and a description of the data-processing functions to be included in the system. After thorough review and approval by management, the specification will also include detailed designs for each separate module of the information system, complete operating procedures for the personnel who will use the system, a test plan to verify that the system works as planned, and resource plans that show the cost, manpower, schedule, and milestones for the project.

The project should be phased from milestone to milestone in order to permit management to maintain control of the process and to measure progress against the plan. A milestone is more than just a date on the calendar; it is a date on which a specific scope of work is to be accomplished and on which a management decision is required. The purpose of the milestone is to force management to look at the plan and decide whether to proceed without modification or to adjust the plan to fit the situation.

Management must be involved in every stage of the plan. This is absolutely essential to the success of the information system because it is a system to serve management, and no one but management itself can represent management's requirements. Technical personnel should be trusted to design a system properly to meet management requirements, but they should never be trusted (or empowered) to establish capability needs. Suffice it to say that an information system should satisfy the needs of the people who set the requirements for it.

DEFINING THE PROBLEM

Problems concerning the availability of existing data, the source of new data, and the timeliness of data must be searched out and clearly defined. Quite frequently a problem does not exist. Consultation with an analyst should be the first step in determining the existence of a problem. If data are not available in agency files, but are available in the statewide files, a problem does not exist. It may involve work and cooperation to get those data in the appropriate format and language, but it is not a problem that justifies gathering the data in a duplicate manner.

A manual function should never be automated without a long period of dual operation. When in doubt, discontinue use of automation. Do not stop the manual system until the "nonexperts" in the organization think that automation is better. Some problems can be identified by answering the following general questions:

1. Does the agency need improved personnel information reporting?
2. Does the agency need an improved payroll system?
3. Does the agency need improved budgetary information reporting? Does the budgetary information match the accounting method? Is there a need for manpower planning reports separate from personnel reports?
4. Does the agency need improved accounting information reports? Must the agency develop a supplemental accounting system to get the financial data needed (a) to manage construction contracts or (b) to manage highway maintenance programs? Must the agency develop a supplemental accounting system to satisfy the accounting specifications of the Federal Highway Administration? How many accounting methods must the agency maintain?
5. Does the agency need improved purchasing information reports? Does the agency need a supplemental physical property inventory system? Does the agency's accounting system provide adequate purchasing information?
6. Does the agency need improved financial management reports for business activities operating within one agency? Is the computer installation provided with adequate financial and product management reporting? Is the vehicle fleet installation provided with adequate financial and service management reporting? Are all business activities provided with financial and product management reporting?

DEVELOPING ALTERNATIVES

When the problems have been defined by comparing existing data and information with the actual needs of the manager, the next step is to define alternatives. Compatible procedures and systems are necessary. As a base for developing alternatives, I use three levels of data processing system design: (a) the simple system, (b) the integrated system, and (c) the management information system.

The simple data processing system consists of a large number of independent transaction-oriented tasks that summarize inputs to produce reports. The user in this case is supposed to be the chief executive of the organization, and he may actually receive the reports himself. After seeing the volume of data contained in the reports, however, he usually sends them down the line until they reach clerks who are assigned to analyze them and prepare a summary of the significant aspects. The analysis passes back up the line until it reaches the chief executive in the form of a briefing by his staff managers referring to handwritten notes. Several points are clear:

1. The system serves the clerk not the executive;
2. The system does not generate the information needed by management;
3. The system permits data interpretation at such a low level that distortion is possible; and
4. The information that finally reaches top management has been filtered by several people according to their concept of management needs and not according to a rigorous statement of management's needs.

This type of data system is valuable and very satisfactory when it is meant to support the clerical worker as in a billing operation. When the system is meant to support management decisions, it will be both frustrating and inadequate.

The simple data processing system is limited to the manipulation of single elements of data. Its output is in the form of status reports on each element. The simple system looks at each part; it does not recognize the whole.

Integrated data processing attempts to show how various elements are related to each other. It structures its contents so that facts can be extracted according to many different criteria. The ability to answer series of questions, as discussed earlier, is typical of an information retrieval system based on the availability of a structured data base into which a considerable amount of data about each administrative activity has been integrated. An integrated data system provides for a single transaction to update several files and thus be available for personnel, payroll, budgeting, and accounting information.

The major problem of building an integrated data system is its cost. The high cost of the system is due to the need for a thorough understanding of all the interrelationships that exist in the organization. Most operations get along adequately without this information, and it is very time-consuming to obtain it. The cost is also affected by the need for new procedures to ensure that all the data needed to update the files are properly acquired and submitted. It is no longer possible for one department to establish and operate its own data processing job; this task now involves the joint effort of virtually all segments of an organization.

Are the benefits to be accrued from an integrated system worth the effort needed to establish it? The answer to that question depends on the nature of the organization involved. In general, the larger the business and the more aggressive is its growth plan (or the more critical its performance objectives in the case of government agencies), the more valuable is the integrated data system. This is also the case with decentralized organizations with multiple geographical facilities.

In those organizations where an integrated system exists, the potential savings due to the improved knowledge of business affairs and the improved ability to bring together diverse facts needed to answer questions are thought to pay for the system many times over. However, this cannot be substantiated because of the dearth of actual data on the financial benefits of such systems. The trend, however, is in the direction of increased use of integrated systems, particularly among those organizations that have been using computers for a number of years. The reason is that these organizations anticipate a number of use-integrated systems for advanced planning and decision-making. This means they are looking forward to having a management information system in 5 to 10 years.

The management information system is the culmination of the lower levels of information handling capability. It possesses all the capabilities of the simple data processing system, the integrated system, and the information retrieval system. In addition, it is characterized by additional programs that permit the user to perform a wide variety of "scientific" management algorithms. The ability to apply these algorithms at opportune times has great value to management.

An integrated system for a highway department could combine, for example, data on soils with data on road inventory and construction unit price, which could be used to help define project priorities. These projects could be manipulated by management algorithms to create a program of projects. This program would enter the budgeting system and through the use of algorithms and combinations of personnel, payroll, and accounting data generate an operating budget, with alternatives.

The main difference between an integrated system and a management information system is that the information system not only permits analysis of historical data but also permits the simulation and prediction of the results of alternative courses of action. An integrated system may provide reports on relationships that management did not realize were significant. In any case, the information system should be responsible to management's changing needs for information. It should direct output data to the right level of the organization and not bother upper management with data that are not relevant to its needs. It should keep track of trends in the data it is processing so that it can give warning when the existing algorithms are becoming obsolete and should be re-analyzed and, perhaps, replaced.

Because managers want different data at different times, the information system should be easy to change with respect to the data it contains and the programs it can execute. In some cases, the convenience of access to the data is all-important; accordingly, the information system should permit direct inquiry from terminals in the manager's offices. The information system should be able to do all these things efficiently and economically while still producing all the reports and documents needed at lower levels for the routine conduct of the business. The difficulty of accomplishing these things is the main reason why true management information systems are hard to find in practice.

An integrated system with integrated manual procedures is a logical and desirable first step because it shows the normal flow of information among the administrative activities. The budget system feeds data to the personnel system and sets up the accounting methods; the personnel system feeds the payroll system; the payroll system feeds the accounting system; and the accounting system receives all management data and returns its information to other systems, especially the business systems.

This information flow must be compared and designed according to the agency responsible for providing the data, maintaining the data, and generating the information. If new data are needed, these responsibilities are established separately for each requirement. When the information flow is designed, the defined problems should be ranked in priority order. When ranking is complete, the problem should be grouped into areas of output information for which new and separate systems could be developed. Then, based on an economic evaluation as well as on a technical analysis, a single system could be selected that, if developed, could produce a benefit in terms of improved management.

The implementation plan should include handling input, file organization, communication with the system (retrieval), on-line considerations, graphics, and classes of users.

RECOMMENDATIONS

The question has been raised whether it is feasible to build an administrative management information system. Certainly, the capabilities exist for information systems that do all sorts of functions such as information retrieval, manipulation, report preparation, and display. Is it possible to build such an information system? Perhaps it is not.

What more is needed to make existing information capability qualify as an administrative management information system? The information system needs foreknowledge of what decisions will have to be made. Without that it is impossible to know whether the output of the information system is going to produce the information the manager needs to make the decisions. The manager's job is to make decisions under conditions of uncertainty. Whenever a situation occurs often enough that a procedure can be developed to handle it, it becomes routine and no longer requires management decisions. Thus, the manager is always dealing with problems that are new. He must acquire all the information that appears to be relevant to the situation, fill in the gaps by drawing on his experience and his intuition, and use his judgment to make what appears to be the right decision. The odds that he will make the right decision all the time are poor; however, if he makes the wrong decision, he usually has an opportunity to correct it. Over a period of time, he can gradually determine the right solution and add it to his experience file.

Because this cycle is typical of all managers, managers do not know what information they need to do their jobs. They may think that the same data can be used to solve many problems, and they may be right. Invariably, though, they will also need data that they never had occasion to use before. The information, which is a measure of the uncertainty in the environment, cannot be foreseen and cannot be provided by the information system. Enlightened managers will realize this and insist that their information specialists maintain a high degree of flexibility to respond to management's requirements.

The proper way to develop an information system that helps the manager is to build it in increments. The first step is to integrate the data that have been used in the past and test them to see how well they work as a management aid. During the evaluation,

those things that do not work well will show the designers what to change in the basic system. The next phase can incorporate improvements and delete items that are irrelevant.

Each phase comes closer to satisfying the current needs of management, partly by making the interaction between the manager and the system more comfortable and partly by making the information output more relevant. This system is effective also because it establishes a feedback loop between the decision-makers and the information system. Each makes incremental changes in its behavior so that the two together improve the decision-making process. The design of an information system that can grow under these circumstances is difficult, but it can be done.

The principal information that the chief executive needs is information that helps him to prepare and support his organization budget. This requires a type of integrated budgeting and accounting information system. This can be expanded, over time, to include personnel and payroll, and it can be linked to the goal and objectives process of planning and its socioeconomic data base and analyses.

As long as the chief executive bases his decisions on emotion as much as on fact, he will never find the output of a data processor adequate to his decision-making needs. Is a management information system feasible? In these terms, the answer is no because the system never provides more than a portion of the information the manager needs and, in fact, never provides enough information to make the decision. If it did, the machine could make the decisions.

In summary, what I have really been demonstrating is that, no matter how sophisticated data processing skills become, men, not machines, will be making the decisions.

DEVELOPMENT OF FINANCIAL MANAGEMENT INFORMATION SYSTEMS

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Financial reporting systems in the highway industry have generally been designed and developed to serve custodial accounting needs and to provide information required by statewide systems and the Federal Highway Administration.

Few states have tackled the major job of implementing meaningful financial reporting systems for management action. Departments of transportation, highway commissions, and other government organizations are the most difficult areas in which to develop satisfactory financial management information systems because there does not exist a good overall measure of the efficiency or effectiveness of a government unit. This is why more government organizations have not adopted better financial planning and control techniques. Although profit provides a good overall guideline for the businessman, he uses many other tools to evaluate his internal progress—many of which could be used by government units.

Financial reports prepared for management show the results of management's planning, coordinating, and control efforts. In describing the past, a report attempts to influence the future by motivating people to take necessary or desired actions. Financial reports need not be rigidly structured or precisely scheduled. In fact, many reports should be issued at random intervals when useful information can be presented to decision-makers. No one approach to presenting financial data to management has gained general acceptance; the format of financial reports should be adapted to the particular environment in which the reports are to be used. The principal test of effectiveness of the design of a financial report is its ability to gain the desired responses from the users.

Two recent advances in computer data processing, the planning for large data banks using direct access devices and improvements in data communication facilities, should lead to less rigid structuring of financial reports. Those advances should also give the user greater flexibility in designing the report structure that best meets his information needs. Decentralized computer terminals not only permit an individual access to information stored in computers but also allow him to specify the information required and the format in which the data should be presented.

Despite advances in information analysis and computer technology, many of the fundamental principles guiding the design of financial information systems retain their validity and usefulness. These include an understanding of the principles of communication as applied to financial reporting, the rules to be observed for selecting information to be included in financial reports, and methods for structuring, implementing, and maintaining financial reporting systems.

A report of any type is an attempt to impart knowledge, thoughts, or facts from one person to another with the expectation that it will add to the knowledge, welfare, satisfaction, and capability of the user. In this projection of information and attitudes, the expectation is not only that the user will receive the messages but also that he will take the action dictated. As such the report has a motivational impact. To impart information to the user and to motivate him require that the rules for effective communications be observed.

As applied to financial reports, the more important rules of communications are as follows:

1. Use terminology that is meaningful to the recipient. Accounting is a technical

discipline and, as such, includes terminology that has special significance or emphasis only to an accountant. Because the users will include operating and administrative personnel, technical accounting language should be avoided and language understandable to the user should be used. If data are best understood by the user when presented as graphs or as operating statistics, these formats should be used rather than tabulations.

2. Apply existing knowledge of human behavior traits to improve the report process. How information will be accepted and put into effect is as important as what information is communicated. It is the human reaction to the report that is the link between receiving information and taking action. Consequently, financial reports should motivate the user as well as inform him.

3. Recognize that particular actions originate with people responsible for implementing the action. Usually, information that people consider most interesting and await most eagerly is that which describes activities over which they have authority and responsibility for developing and implementing plans of action. The closest delineation of these areas of interest is the organizational chart; therefore, it is useful to organize financial reports in terms of organizational units and to report for each organizational unit the income and expenditure of operations within that span of control.

4. Avoid excessive information, for too much information hides rather than reveals significance. Frequently there are too many conflicting, duplicating, or unnecessary reports full of useless or marginal data and excessive analyses and detail. This frequently leads to superficial perusal of the report and consequently much wasted effort.

5. Emphasize important information and direct attention to meaningful and significant aspects of the report. Exception reporting emphasizes departures from plans or control objectives. This technique compliments the reader because it recognizes that he is too busy to analyze all details of the information presented.

6. Ensure that essential information that highlights basic problems or has a major bearing on planning and control activities is included. Frequently control data requirements cannot be limited to costs or other performance criteria that can be expressed quantitatively or included in the accounting system.

7. Distinguish between information needed for different purposes and do not expect that reports designed to attain one objective will necessarily serve many other requirements.

8. Recognize that planning and control are substantially different functions, and reports developed for control purposes will not necessarily meet the information requirements for planning. Planning is program-oriented, whereas control information is organization-oriented. That is not to say that programs should not be controlled; however, their control is usually the result of controlling resources allocated to an organization to perform the program. Failure to distinguish between these two different types of information requirements usually results in overemphasizing one type of information, de-emphasizing the other, and confusing the reporting structure. It can result in developing the wrong type of information, which is sent to the wrong people who compare it with incorrect measurement criteria.

9. Prepare reports that are accurate, prompt, logical, and clear. In many cases it may be desirable or necessary to include production as well as financial data. Unless information is sufficiently accurate to describe an event or situation, there will be little confidence in financial reports. The information presented should be current; a late report is almost as useless as no report. The scheduling of reports should be influenced by the situation reported. Information that can be used immediately should be reported as the events occur; information that allows for longer periods of effective response can be reported when required. The frequency of reports also depends on the situation encountered. In certain circumstances flash reports can be issued on a random basis as an important event occurs. Other report requirements may be established on a daily, weekly, monthly, quarterly, or annual basis.

10. Consider utility versus cost of preparation. Unless a report's contribution to the company is greater than its associated cost, its preparation need not be encouraged.

It should be remembered that the major interests of management revolve around planning, coordinating, and controlling activities. It is the function of financial reports

to provide much of the information needed for these activities. Financial reports, however, are not substitutes for management; they are part of the process by which management is informed and permitted to make decisions and to take action. Information included in financial reports should be carefully chosen with the object of coordinating and integrating the information toward well-chosen objectives. Financial reports should include data on the overall economic environment, key economic factors within the organization, important performance elements that control results, and the definition of planning and control data that are required to ensure results.

The development of information requirements that describe performance and influence operations can be initiated by defining the major functions where planning and control measurement criteria and current information on results are needed. These broad functions are then identified by organizational components where planning and control data are required individually to gain satisfactory results. Major information requirements for planning include overall operating results, financial position, status of major programs and projects, results of research and development efforts, administrative services, and allocation of personnel and material resources. Control information requirements classify these major areas into organizational entities and establish the key performance measures in each one of these areas that best show the effectiveness of performance. These performance measures generally include only those that can be quantified and that have an impact on costs. They are developed by the selective application of all types of measurement techniques.

The sources of information included in financial reports are varied. Most of the financial information flows from the accounting system, which records, classifies, and summarizes financial results based on the chart of accounts and according to accounting rules. Comparative data are usually taken from accounting records of previous periods or are computed by multiplying measurement criteria representing the rate of incurrence of an expense, if efficiently performed, by the level of activity. These data are compared with actual results of operations. Additional information in financial reports may include departmental statistics, personnel information, research and development results, labor productivity, inventory levels, political consideration, and economic trends and conditions.

The structure of financial reports includes formal design, techniques used in presenting information, level of detail reported, and methods used to integrate, highlight, and report by responsibility centers. The development of a financial reporting structure is a complex undertaking because it must respond to many different requirements, starting with the general considerations outlined here. The designer of financial reports must also recognize the different amounts of detailed information needed by the several organizational levels. Information included in financial reports must flow from one reporting level to the next in an integrated manner so that the information communicated is consistent, thereby permitting each level of management to communicate with the other. The reports should be designed to recognize where decision-making authority exists so that the individual responsible for an activity is informed of the results of actions taken.

Usually the commission is interested in broad policy and planning problems and overall financial results because its function is to guide, plan, evaluate, and approve major plans and decisions of other executives. Subordinate managers emphasize the development of major planning strategies, but they are also vitally concerned with control data to ensure the attainment of their objectives. Department managers participate in the planning process, but their major thrust is in the controls area to ensure that their operations are being performed as efficiently as possible within the approved scope of operations and established programs.

Once the broad areas of information requirements are established by organizational hierarchy, it should be recognized that descending levels of authority require more intimate knowledge of operations than do the summarized results reported to higher authority. In summarizing results, however, it is essential that the information flow be integrated.

When financial reports are designed, the characteristics of the organization and the attitudes and information needs of the users should be recognized to the greatest extent

possible. Executive management usually requires, as a minimum, a monthly financial report on operations. Although the format and content of monthly financial reports vary considerably, the reports usually include a highlights statement, a comparative balance sheet, and reports of operations summarized, if appropriate, on an organization, division, and department basis. The highlights statement should be supplemented by comprehensive reports on program accomplishments or problem areas where information of this nature is significant. It may not be necessary to report on each program every month. The emphasis in the report can be shifted from month to month to different functions, and program results should be compared with the assumptions and expectations on which each program was based. Graphs should be used to reveal current trends as well as projected results.

The report of operations presents a comprehensive overview of operations on an organization-wide basis. It accomplishes three basic functions. First, it illustrates by major divisions or operating entities (a) the magnitude of the changes in planning premises of plans originally approved prior to the beginning of the fiscal year and (b) the current view of what results will be for the current year. This information is useful because some opportunities for adjusting or modifying plans and programs generally exist. Second, it reveals the efficiency of executive and supervisory personnel by showing the performance of their units. Third, it compares the overall actual results of operations with the prior year and reveals planning and control variances by major areas of operations.

All of the efforts devoted to the design of a financial reporting system will be wasted unless the system is implemented properly. This requires patience, understanding, and ability to communicate the objectives of an information system. An information system is not a substitute for management: It cannot act; it cannot make decisions; and it cannot evaluate people. It is merely a process by which data are collected, classified, analyzed, compared, and presented so as to give meaningful information to the user.

After the rules of communication have been observed, the information needs satisfied, and the financial reports designed, the financial reporting system must be explained in detail to each user. Where the financial reporting system is an integrated one, the entire system is as weak as the weakest person in the chain of communications. Each communicator must talk about the same information content in the reports. Detailed information must generally be solicited from subordinate levels, and explanations of variances from plans or control objectives must be obtained from the point at which actions occurred or where the plans were made. For explanations to be meaningful and useful, the subordinate management must have a clear understanding of the meaning and significance of variances and of the strengths and weaknesses of the measurement criteria used to establish the variances and confidence in the integrity of the measures used. It must also have understanding of and confidence in the accounting system used to develop the financial reports.

The designer of the financial reporting system must realize that the preparation of reports is not the objective of the system. The objective is to motivate people to take certain actions. He must be able to overcome the instinctive reactions of people against being reported on and establish the financial reporting system as the instrument of the user rather than a device of the financial organization. For the financial report to be useful, the user must feel that the measurement criteria are fair and reasonably accurate and that conclusions resulting therefrom are logical. He must also see a direct benefit in the use of such information in terms of understanding his problems, reaching better decisions, managing people more effectively, and, in general, making better use of the company resources entrusted to him.

To accomplish this, all management levels reported on should participate in the design of the financial reporting format; they should express their preferences for how data are presented and should share in the development of the measurement criteria associated with their activities. This will lead to improved understanding and use of financial reports.

With the developing sophistication in problem analysis and problem-solving techniques, the demand for financial information will in all likelihood continue to increase. Under such circumstances it is relatively easy over a period of time to increase the

number of financial reports issued, many of which may serve only a current need or provide little or no useful information. Therefore, before new reports are issued, their potential usefulness should be carefully reviewed by each proposed user to ascertain if the report is worthwhile. This review frequently can best be made by representatives of executive management and the financial and data processing departments. The proponent of a new report should be required to justify its preparation.

Periodically it is advisable to review existing reports to determine whether they are serving a useful purpose. Each user of the reports should be asked the following questions:

1. Is the report very useful, fairly useful, or not useful?
2. Why have you classified the report in this manner?
3. How is the report used?
4. What actions does the report prompt you to take?
5. Is the report timely, accurate, and informative?
6. Should the report format, frequency, or content be changed?
7. Are measurement criteria sufficiently accurate?
8. Are improved measurement criteria available but not used?

Answers to these questions help determine whether the financial reporting system is changing sufficiently to meet management needs for financial information without becoming too burdensome.

The development and installation of a financial management information system is an art, not a science. When such systems are properly conceived, approved by management, and effectively implemented, they can be extremely helpful in increasing the effective use of resources through better planning and control.

Although control is important and has in many cases been the motivation for the implementation of such systems, I believe the opportunities presented to improve planning and to broaden the manager's perspective in terms of his responsibilities for financial planning and control are far more important.

AUTOMATION ACCOUNTING, BUDGETING, PERSONNEL, AND OTHER INTERNAL ADMINISTRATIVE ACTIVITIES

Roger R. Shipley, Illinois Department of Transportation

BUDGETING

A problem with budgets that is common to all but a very few states is that of obtaining legislative sanction, i.e., appropriations. Getting appropriations approved requires an educational process because nearly every session of a state's general assembly has new members on the committees that review requests. The makeup of the assembly changes each election; therefore, a different degree of friendliness will exist after each election, and the education of the administrators as well as of the legislators will require revision. To meet the requirement of educating legislators and their staffs, we explain to the members of the committees with whom we deal our budgetary objectives and the financial cycle within the budget year. We use a package that explains these objectives and includes an actual example of a budget status report. We believe that this helps ensure that the members of the Illinois General Assembly who are most directly concerned with the Division of Highways' appropriation are aware of our objectives and that we manage the highway user revenues on a business-like basis.

In regard to functions that may be included in the area of fiscal management I believe that the budgetary activity of preparation, execution, and monitoring is by far the single most significant function. The budget function is, or should be, the beginning of the chronological order of events to assemble and direct all other functions whether they are general accounting, cost accounting, staffing, auditing, or reporting. This is to say that all other systems must be consistent with and complement the organization's budgeting system.

The Illinois Division of Highways is divided into approximately 100 budget (organizational) units, each of which is responsible for the preparation and justification of its own annual budget and the eventual allocation of this budget into quarterly allotments. The Budget Section of the Bureau of Fiscal Management assists these units in their budget preparation as well as in scheduling and conducting hearings between top and operating management. The individual budgets are reviewed and modified as necessary and then consolidated to arrive at a total appropriation request for the Division of Highways.

After the rigors of obtaining legislative appropriations are completed, the operating budgets must be finalized and each budgetary responsibility must be allotted its share of the funds. Again, automation is a valuable adjunct to management in monitoring operations through the current year. We make a tentative apportionment to a given budgetary responsibility for its share of an appropriation and request that those responsible submit their quarterly allotment request. These are reviewed briefly, and the data are entered into the computer system. The chief of each budget unit is responsible for seeing that his unit operates within the approved budget. To help him in this responsibility, the data processing section prepares a monthly budget status report, a copy of which is also given to the budget officer.

Basically, the information in a budget status report shows how much of the current quarterly allotment for each appropriation limitation has been obligated, committed, and expended and how much is still available for the balance of the quarter. The budget officer also reviews each of the reports to determine whether each unit is properly operating within its budget. When any overexpenditure or unusual underexpenditure

in an appropriation limitation is noted, the unit chief must explain and justify the reason for the situation. Corrective measures are taken for continued unjustified budget violations.

The unit chiefs are given an amount of flexibility in the operation of their budgets by having a portion of their total allotments carried in a reserve rather than allocated to a specific quarter. The allocation of any part of this reserve, however, must be approved by the chief highway engineer. Any changes to the approved budget and allocation plans must be submitted to the budget officer.

Without automation of budget status reporting and analysis, the monitoring and compliance (planned versus actual program accomplishments) activity of an otherwise sound budget system will be rendered ineffective. This is to say that the budgetary activities of preparation, justification, and execution will be only as effective as the organization's ability to perform status reporting and analysis of the original program objectives.

PERSONNEL

A few features that we are using in our personal services control system are of considerable importance to management. As mentioned earlier, the Illinois Division of Highways has approximately 100 organizational units that have specific budgetary responsibilities. Figure 1 shows an actual page of the personal services control system (PSCS) report for one of these organizational units, the Data Processing Section. Position title and code, location, employee's name, work basis, and monthly salary are indicated, and the number of positions authorized, budgeted, and filled is indicated. For example, under one of the position codes for data processing analyst II, two are authorized, two are budgeted, and two are filled, and under another position code for data processing analyst II, two are authorized, one is budgeted, and two are filled. In summary, we have four authorized, three budgeted, and four filled. More positions filled than budgeted would indicate to the manager that, unless there were sufficient offsets elsewhere in budgeted positions, his budget would show a deficit at the end of the fiscal year. In short, PSCS reports give the manager his dollar projections. Also, this system can be used to project annual budgets. Many different summary reports of benefit to management may also be obtained through automated techniques. For example, we could list positions by classification for the entire division, list a given classification such as the number of clerk typists, or list positions by categories such as professionals, laborers, and clerks.

We are developing an automated personnel management system that should produce many benefits. For example, additional training or education received by employees would be added to their master file. If a particular skill were called for in a given task, the computer would search records quickly to determine who possesses the required skill. Or, if certain skills needed to be developed further, the file could be easily scanned to determine which employees possessed the prerequisites for the additional training.

ACCOUNTING

Timeliness of accounting information is one of the key elements to good management control, and in this area automation can give significant dividends. Teleprocessing applications whereby data may be entered on-line from a district or field location is becoming more widespread. These applications sometimes consist merely of updating a file; in other cases they may consist of printing a voucher, recording the transaction on a summary tape, and making both the hard copy and tape available to management. The system cannot yet make direct entry for payment to vendors, but we are actively pursuing this application and have a target date of June 30, 1972.

Currently, we are entering from field terminals certain cost distribution, such as the labor reporting, that gives us the information required to prepare federal billings. Other computer applications are organized in the following general areas: bid lettings, contractors progress payments, federal billing system, on-line payroll system, employee position control system, budget status system, vendor expenditure analysis, and cash flow. The following applications are being worked on: on-line vendor voucher

Figure 1. Position status report.

APPROPRIATION	6017 - elec. Data Processing	REPORT NUMBER	APS-RO04
RESPONSIBILITY	8015 - Central D.P. Staff	REPORT DATE	02/28/71
		RUN DATE	03/30/71

POS TITLE	POS CODE	POS LOC	EMPLOYEE NAME	WORK BASIS	MONTHLY SALARY	ANVT DATE
TITLE SUMMARY TOTALS						
		POS AUTHORIZED	1	MAN-MONTHS WORKED		.0
		POS BUDGETED	0	FUNDS DISBURSED		\$0
		POS FILLED	0	OVT FUNDS		\$0
.....						
DA IN SUPV II	11412-23-02-202-22-01	084	BAER, GERAL	71	796	
TOTALS	POS AUTHORIZED	1	POS BUDGETED	1	POS FILLED	1

TITLE SUMMARY TOTALS						
		POS AUTHORIZED	1	MAN-MONTHS WORKED		1.0
		POS BUDGETED	1	FUNDS DISBURSED		\$796
		POS FILLED	1	OVT FUNDS		\$0
.....						
DA PR ANL I	11421-23-02-201-10-01	084	HEAD THOMA	71	899	
TOTALS	POS AUTHORIZED	1	POS BUDGETED	1	POS FILLED	1

DA PR ANL I	11421-23-02-202-10-01	084	STRAHM FRE	71	999	
TOTALS	POS AUTHORIZED	1	POS BUDGETED	2	POS FILLED	1

TITLE SUMMARY TOTALS						
		POS AUTHORIZED	2	MAN-MONTHS WORKED		2.0
		POS BUDGETED	3	FUNDS DISBURSED		\$1,897
		POS FILLED	2	OVT FUNDS		\$0
.....						
DA PR ANL II	11422-23-02-201-10-01	084	GIGANTI NI	71	1081	
DA PR ANL II	11422-23-02-201-10-01	084	MESSINGER	71	1081	
TOTALS	POS AUTHORIZED	2	POS BUDGETED	2	POS FILLED	2

DA PR ANL II	11422-23-02-202-10-01	084	PACK REBEC	71	1025	
DA PR ANL II	11422-23-02-202-10-01	084	LAME HAROL	71	1081	
TOTALS	POS AUTHORIZED	2	POS BUDGETED	1	POS FILLED	2

TITLE SUMMARY TOTALS						
		POS AUTHORIZED	4	MAN-MONTHS WORKED		4.0
		POS BUDGETED	3	FUNDS DISBURSED		\$4,091
		POS FILLED	4	OVT FUNDS		\$0
.....						
DA PR ANL III	11423-23-02-201-10-01	084	SUNDIN ROB	71	1243	

system, personnel management system, contract cost estimating system, on-line budget status system, project control system, and right-of-way control system.

William G. Ainsley, Wyoming State Highway Department

Highway departments must be made aware of the many advantages that automation provides. Highway personnel, especially district engineers, must be shown that automated systems offer greater control over operational procedures than do manual systems, thereby creating more efficiency within the district and providing for a more economical operation.

Of particular concern to the district engineer is maintaining financial control over the many work programs and projects for which he is responsible. It should be quite apparent that, when data used for financial management are current, the district engineer is in a position to make better decisions and develop more efficiency in the district work program. When financial management information is received after work has been performed, the district engineer cannot be expected to exert much control

over his operations. A lack of current information is not an unusual situation in many highway departments; in fact, it is the rule, not the exception.

Consider the impact of a system that would provide current and useful data for all echelons from the chief administrative officer to the district engineer. How much more efficient would the highway organization be if useful current information could be provided through automated processes? Logical application of these data could include maintenance budget control or project costs, operational budgets, personnel information and records, and other items of a general administrative nature.

Such systems are within the reach of all highway departments. Conversion may require a reappraisal of current policies and a revision in management philosophy, but it can be done by improving the accounting system as follows:

1. Convert the current cash accounting system to an accrual system;
2. Increase the timeliness of financial information through implementation of non-cyclic accounting principles;
3. Develop management-oriented financial reports that engineers can understand;
4. Incorporate management by exception reporting throughout the financial task wherever possible;
5. Simplify user coding by placing more of the coding load on the computer; and
6. Design the basic accounting files in such a way that organizational units other than the accounting division can directly examine those files.

Changes in procedures are delicate operations and must be preceded by preparation for change. This is why selling the program is so important if successful implementation is to be achieved. This is true at the district-engineer level as well as at all other levels in the organization.

AUTOMATION AND ITS COMMUNICATIONS VACUUM

Jack Stanton, Arizona Highway Department

The "technical revolution" has produced concepts that are difficult to communicate clearly. The field of data processing/automation is certainly no exception in this respect. Colloquialisms peculiar to the data processing field have hindered effective communication between data processing personnel and management. In most instances, computer personnel sincerely try to communicate and provide the service function they represent, but many times they lose their audience because of the terminology they use.

Language is not the only barrier to effective communication among highway personnel. The complexities of modern highway business demands up-to-date information, and major resource commitments must be made to develop on-line, data-oriented information systems. We no longer can think in terms of the "payroll system" or the "federal-aid system." They all should be incorporated in a total financial segment of a management information system (MIS).

Another problem to be solved if automation is to be developed properly to serve the total needs of highway organizations regards the interdisciplinary confrontations experienced when developing an information system. Because the computer hardware capabilities have virtually removed the limitations of distance and time, we can no longer justify what I call "technical islands" of systems development. All organizational units must now gain an understanding of one another's responsibilities and how their efforts contribute toward the total goals and performance of the organization.

Another contributing factor to the communications vacuum is that too often the user (including management) does not exercise his responsibilities. In the early stages of automation, data processing personnel were eager to serve and accepted some functions that can only properly be executed by the user. In many respects this has not changed, especially in such areas as control, balancing, documentation, report format determination, and report distribution. Data processing personnel cannot serve as management and must not try to do so.

The belief that only the programmer can understand computer capability must also be overcome. Details of programming techniques are not required of the user, but a basic understanding of how an automated system is built and functions is essential.

How can this apparent overall communications problem be solved? We should start by removing the "magic" from how automated systems really work. Then, on a case-by-case basis, we should determine whether automation is appropriate and can truly solve the problem. Problems caused by improper supervision or bad manual systems design can many times be solved by methods other than automation.

The requirements for doing business today are many and require a multidiscipline approach to solving information problems. The formation of project teams that are composed of management analysts, systems analysts, and programmers seem to be one practical solution. Implied in this approach is the policy that the systems to be automated should have goals and objectives. If one cannot specifically define a problem and the proposed solution, chances are the solution is not sound and will fail. Thorough study and planning are essential; one must establish the number of people and amount of funds needed to do a pilot study in which simulation models are used to verify the paper plan. Too often we move directly from the paper design to the real world without making a pilot study.

There should be a top management advisory group that reviews the automation project requests, helps assign priorities for development, and endorses the commitment

of resources to accomplish the tasks. This should not be a rubber-stamp committee but rather one that represents the total interests of the organization. Many times it is at this level that the interrelationships of proposed changes can become more clearly defined. After implementation of any new system, a follow-up review or audit should be performed to see whether the system is performing as planned.

Finally, the importance of using computers correctly must be transmitted to all levels. As we commit more and more work to automation processes, we become more dependent on them for survival.

ROADBLOCKS TO EFFECTIVE MANAGEMENT OF AUTOMATION

Marvin E. Hermanson, Minnesota Department of Highways

Many highway departments do not manage their computer personnel adequately. Managers tend to accept unquestioningly whatever they receive from computer professionals. This problem does not stem from the position of the data processing unit in the organizational structure; it is one of management education and involvement. A recent study found that the actual location of the unit in the organization made very little difference as long as it was within two levels of the chief executive. What is essential is that the data processing manager be given an executive role and that he be allowed to interact effectively with the organization's other executives.

In many agencies we find the automation function under the supervision of the chief financial officer. This is a throwback to the early days of automation when the computer functioned mainly as an accounting machine. Though the continued location of the computer unit under finance might seem anachronistic, it has been shown that this too had little effect on the efficiency or quality of computer services. In short, then, the actual location of the data processing section within the organization is relatively unimportant as long as it is high enough on the organizational chart to give it the stature it needs to effectively operate and influence decision-making. What is important in locating the automation function is that it not be isolated and insulated from the remainder of the organization. Regardless of its physical location, the data processing section is the central nervous system of an organization.

A problem in many organizations is the decentralized nature of the computer application process. Highway departments are large organizations, and often there is needless duplication of effort by separate divisions. Divisions should develop their own request, and cross-check to ensure that other divisions are not doing the same work.

What are some solutions to these problems? Each department has unique agency-oriented problems; therefore every solution will be a little different. However, there are a few general suggestions that can be applied in all situations. A management steering or review committee should be instituted in each department. All managing levels should be taught how data processing works. Finally, the data processing director should be a member of the management team.

J. T. Kassel, California Department of Public Works

Effective management of automation involves the same principles as does effective management of anything else. These principles are as follows:

1. Planning—setting goals and objectives and developing strategies;
2. Organizing—assigning responsibility, budgeting, and staffing;
3. Directing; and
4. Controlling—monitoring performance and taking corrective action.

Although data processing decisions fit into a defined set of management activities, there are unique management problems in the data processing field. The most common decisions we must make concern the following: feasibility, alternative selection (spec-

ification of results and changes in user operations), priority, schedule, resource allocation (budget), level of service (response time), security of data, and evaluation and approval of results (audit).

DECISION-MAKING PROBLEMS

One of the primary problems in making decisions is the rapidly changing data processing environment. The speed of technological advances in computer capability, coupled with the large development time for many of our systems, creates difficulty in decision-making about feasibility, alternative selection, and level of service. For example, what is not technically feasible today as we begin development of a computer system may be feasible and, in fact, may require a different decision 2 or 3 years from now when the system is finally implemented.

Another problem is that of finding the decision-maker. Decisions on data processing systems do not fit neatly into the line organization chart as do many decisions in well-established functional areas of responsibility. This is particularly true of large complex systems and those that cross functional lines, where an initial decision must be made as to who is responsible for the proposed program. The resulting problem is that many data processing system decisions must be made at a high level in the organization by a decision-maker who has responsibility for all affected functions.

The timing and scope of decisions present another problem. When and by whom are decisions made about alternatives, level of service, security of data, and priorities? Is there but one decision point in the development of a project, or are there several for each type of decision? Is an original decision regarding feasibility of a project a commitment to complete development without an effective opportunity for further management review?

Communications raise yet other questions. Are data processing personnel getting a clear picture of the users' needs? Are data processing personnel giving users all of the information they need to make an effective decision? This is a particularly difficult problem for those decisions and alternatives that will significantly affect the way in which the user operates, i. e., whether the proposed system eliminates activities, merges functions, or requires greatly different skills.

Another problem is competition among users for limited resources. Although this roadblock is not peculiar to data processing, it again requires decisions on resource allocation, priority, and schedule to be made at a high level in the organization.

Although many computer systems have easily identifiable benefits in reduced personnel requirements and operating costs, many others have intangible benefits that are difficult, if not impossible, to quantify. Systems in this category would include those that provide improved management information and information or analysis capability that previously did not exist. It is difficult, for example, to estimate the value of being able to examine many alternative structural or highway designs.

An effective plan for data processing systems development is the key to solving problems created by automation. This plan must include top management direction and the objectives of the user so that guidelines and procedures can be developed that will allow delegation of decisions to appropriate levels. The plan should include top management's goals and policy, level of data processing effort, degree of in-house operation versus contracted work, centralized versus decentralized operations, and system development. Trends affecting data processing should be defined for various functional areas. The highway department's commitment to an automated accident surveillance system, automated design procedures, and maintenance management system should be clearly outlined so that all levels of management are following the same plan. The plan should also contain estimates of resource requirements so that department management can provide for proper budgeting and staffing.

The responsibility for each system decision should be assigned. The plan should indicate who is responsible for cost-benefit estimates, which decisions are appropriate for districts and headquarters managers, and which decisions should be made by technical personnel and which by management. There is no easy answer for multifunctional

systems, but the responsibility must be assigned to either the manager of one of the user functions, a committee, or a higher level manager.

The system development process should also have definite decision points. This allows the user and top department management to make better decisions on resource commitment, priorities, and schedules. As a minimum, decision checkpoints should follow a feasibility study or conceptual design, detailed system design, coding and testing, and a post-implementation audit to ensure that the system performs as expected. These checkpoints are analogous to those in the development of highway plans, i. e., a planning study with approval of a project report, review of geometrics and other design features, buying the constructed highway improvement, and follow-up operational review.

The data processing system development process should include a communications and work-flow network that requires users to be sufficiently involved in the functional area systems. This includes decisions on feasibility, priority, training needs, and level of service. The process should also guarantee that all requests for data processing be identified and then evaluated by the proper level of management so that no request is ignored and no systems development is begun without appropriate management approval.

My suggestions certainly do not provide a complete solution to all of the problems encountered in making data processing system decisions. However, they are the essential elements of a management process for development of data processing systems.

Eugene Bardach, IBM Corporation

Maintenance of computer software is in many ways analogous to maintenance of highways. It is not necessarily the additional mileage that creates the maintenance problem even though it is a factor. Developing and maintaining the complex variety of computer software are major functions of data processing staffs. Highway departments have for a long time utilized engineering consultants, and I submit that they should investigate the use of data processing consultants. These consultants can offer specific capabilities that the highway department cannot maintain in its staff.

The data processing consultant for computer software should carry the project through its entire course including maintenance. I am leery of those who are willing to design a system but are not willing to go further. My major complaint is that they gain a lot of expertise relative to the problem in the analysis and design phases and then leave with that expertise. The highway department pays for the departed knowledge. There is a trend toward performance clauses in software contracts. Of course, one must expect the cost of the software to reflect the added risk on the part of the contractor.

No highway department can afford to develop all the software it needs whether that development effort be internal or contracted. Great economies can be had if several highway departments join together and contract for a given software system. The difficulty is obviously being able to define a set of requirements agreeable to all. However, complexities and comprehensive capabilities desired in the management information systems of tomorrow will require such cooperative development efforts.

PART IV

HIGHWAY OPERATIONS SYSTEMS

AUTOMATION IN TRAFFIC OPERATIONS AND HIGHWAY MAINTENANCE

Mathew J. Betz, Arizona State University

The purpose of this paper is to review the application of automation techniques in the fields of traffic operations and highway maintenance. To facilitate review of such a broad subject, I have divided the various automation systems into general categories.

DATA INPUT

The most essential part of an automation system is the input of basic information; one must continually emphasize the fact that the reliability, effectiveness, and validity of every system depends on the quality of the input information.

Automatic data input or sensing devices are now used to process much data. The use of these devices is very common in traffic operations; they include the pneumatic, loop, radar, and traditional types of vehicle presence detectors. Television surveillance can also be included in this category.

There are also important manual methods of data input. These include data obtained from traffic surveys, work reports, productivity analysis, census data, and other manually prepared reports. These methods are still important in traffic operations automation and represent almost the sole input of data to highway maintenance systems.

A new type of manual input system relies on reports or observations of individuals supported by electronic or some other type of equipment. Information is supplied by observers using roadside telephones and helicopter radios. Observations are also made in control rooms by the use of surveillance systems. It is likely that this kind of input, which might be called equipment-aided manual input, needs more study and probably has significant application in maintenance operations and in traffic operations on rural systems where completely automatic data collection becomes too expensive.

INFORMATION PROCESSING

Traditionally, the heart of automated systems has been electronic computers that perform the information-processing function. This processing includes tabulation, summations, analysis of trends, comparison of new or current information with either historical patterns or desirable characteristics, and a multitude of other mathematical calculations. The problems associated with this function include the types of hardware and software necessary, the amount of data to be analyzed, the sophistication of the analysis including the amount of core or disk storage, the use of peripheral equipment, and the urgency of the results (the use of prime time versus nonprime time).

INFORMATION OUTPUT

The first information or automation systems produced various reports that were typically concerned with the direct analysis of data, the scheduling of predictable or recurring items, the important function of keeping relatively current inventories, and cost accounting systems.

In traffic operations, much of this output was related to the analysis of historical data, such as traffic volumes and accidents, and resulted in implementation of some traffic control measures, such as reversible lanes on freeways. For those cities that used three-clock, fixed-time controllers on arterial street systems, the phasing and offsets could be determined from fixed-time analyses and information output.

To date, the major application of automation systems in highway maintenance has entailed the use of systems that provide cost-accounting, inventory-control, and operations-scheduling information. The initial application of most automated systems, has involved regularly scheduled, recurring activities. However, as will be illustrated in the following section, the real impact of automation on highway systems is related to its application in unusual or nonpredictable occurrences.

INFORMATION CONTROL

The most dynamic area of automation in the context of this report, especially in traffic operations, is the information-control system. In these integrated systems, the input, processing, and output are designed to provide information directly to the user of the system. In traffic operations systems, the user would be the motorist; when applied to highway maintenance, the user would probably be the individual highway maintenance office. The system bypasses the technician's interpretation of statistical or numerical results and proceeds directly to the issuance of information or orders to those directly operating within the system. This may be done on a real-time basis. Data collection, processing, and reporting times must be short enough so that an effective response or adjustment in the system can be accomplished.

The answer to what is real time and what is fixed time depends on the type of system under consideration. The two categories of highway systems under discussion here offer a good comparison. What might be considered a real-time response for a maintenance system (1 hour to 1 day) could not be considered a real-time response for a ramp-pacer system on a freeway interchange (seconds or fractions of seconds).

In the area of traffic control, there are a large number of information-control system projects that are currently being designed and implemented. The use of changeable-message signs both on freeways and on rural highways is one development. In addition there are ramp-metering and lane-control projects on freeways and in tunnels.

Even the rural road system is beginning to feel the impact of such systems. The development of a simple passing-aid system for rural roads, which would incorporate sensing, some fairly rudimentary information processing, and changeable-message signs, would indicate to the driver when passing is safe on two-lane, two-directional roadways with inadequate passing-sight distance.

One of the most sophisticated systems tested thus far is the electronic route guidance system of driver navigation and routing. This system involves the use of induction loops, transceivers, computers, on-board receivers, and display equipment that indicates to the driver the appropriate route to be taken from origin to destination. The level of sophistication of this system is such that should the driver make an incorrect turn the equipment would automatically register this and display the proper actions for the newly defined optimal route.

Another area that is being developed is methods of communication for information-control systems. These methods include traditional traffic lights, flashing lights, changeable-message signs, a radio that uses a special highway frequency, an interruptive roadside radio, and various types of pacer systems.

In highway maintenance, there has been very little application of information-control systems. As has been indicated, such systems are extremely useful in dealing with nonscheduled occurrences. Such occurrences are as important in highway maintenance as in traffic operations. Emergency maintenance requirements, washouts, snow removal, and other nonscheduled maintenance would be subject to the influence of information-control automation systems.

Much of the traditional maintenance organizational structure has been developed to react to and carry out instructions from an information-output system where schedules of recurring operations can be developed. This is a basic, though tacit, assumption in the development of highly structured maintenance divisions and subsections, each of which is responsible for a well-defined set of highways. If information-control systems are to be meaningfully implemented in any area, including highway maintenance, a great degree of flexibility on the part of the operational or line functions of the system will be required. It is the flexibility of the individual automobile driver that has allowed

such systems to be implemented relatively quickly in traffic operations. In highway maintenance, it can result in the development of greater flexibility in the mobility of manpower and equipment to meet, on a timely basis, maintenance needs over a broader area. This is especially true in states such as Arizona where there are substantial changes in climatic conditions over very short distances. It may mean the tentatively scheduled or unscheduled movement of both equipment and personnel from one maintenance district to another in order to better meet the requirements of the system.

In addition to the use of information-control systems to meet emergencies, such systems would be of significant benefit in the development of flexible scheduling for maintenance operations. This would require the development of a schedule, possibly on a daily or hourly basis, that could be continually adjusted to meet minor emergencies and regularly expected but unscheduled activities such as the replacement of defective or vandalized bulbs in traffic control signals. The application of information-control systems to highway maintenance is difficult because highway-maintenance activities are separated both in time and in space. Thus, it is not a problem of controlling or reacting to conditions at a specific point; it is a major logistics problem that consists of minimizing costs and time losses due to the transport of man, equipment, and materials. Thus, the system needs to be much more sophisticated than most traffic-operation systems, including the possible incorporation of stochastic modeling and other highly complex activities.

Overall, the characteristics of information-control systems are probably best illustrated by the electronic route guidance system. This system, almost by necessity, must be developed on a real-time basis. Its function is to control the system through the communication of information. The system must also have self-correcting or contingency capabilities to provide further information when the initial advice has not been followed. Many traffic engineers feel that traditional lights and pacer systems are direct-control systems. The electronic route guidance system illustrates the point that none of these systems has direct control because the driver may intentionally or unintentionally make the wrong decision. Motorists are less likely to violate signals if they realize the danger in doing so.

DIRECT-CONTROL SYSTEM

In a direct-control system, the input information, data processing, and actual operation of the system are all fully controlled internally. The automated factory is the traditional example of such a system. Although they are currently at the conception stage, fully controlled systems will probably be used in highway operations and possibly in highway maintenance within the near future. In the area of traffic operations, the fully automated highway represents a direct-control system. Here, the individual motorist effectively becomes a passenger, and complete control of the vehicle is exercised by an automation system. Obviously, one of the major problems of such a system as applied to highway work is compatibility. Most direct-control systems usually require considerable, on-board equipment. This means that entrance into a control system would be restricted to those vehicles that have the equipment; it also means that solutions must be found to the problems of equipment repair and fail-safe controls. Because of these requirements, the cost of such a system for highway operations is probably prohibitive at this time. However, future highway capacity probably can be provided only through the use of fully direct-control systems that allow vehicles to travel at high speeds and low headways.

It is interesting that, at least conceptually, some direct-control systems for highway maintenance are simpler and more easily attainable than those used in current highway operations. The opposite is true for information-control systems. The development of the automatic use of heat and sand and chemical spreading on bridge decks to counteract icing could possibly be accomplished by using relatively simple sensing devices, rudimentary information processing, and automatic distributive mechanisms. When the heating of highway pavements becomes economically feasible for major facilities, it will then be possible to have a direct-control, automated snow-removal (for reasonable amounts of snow), and ice-control system. It is somewhat more difficult,

at this time, to foresee applications of the direct-control systems to regularly scheduled, geographically discontinuous maintenance activities such as patching, draining, striping, and taking care of shoulders and roadsides.

One fairly simple method of direct control in traffic operations is the closing of ramps or lanes by the use of gates or other restraining devices. The implementation of fast-acting restraining devices on ramp metering could represent a change from an information-control system to a direct-control system.

SUMMARY

I have attempted to give an overview of highway-maintenance and traffic-operations automation. These systems are rapidly becoming more complex and sophisticated and, therefore, continually more expensive. Therefore, greater care must be exercised in the planning and development of such systems prior to decisions regarding implementation.

Because of the need for planning, the careful and definitive descriptions of what the automated system needs to do becomes increasingly important. It is embarrassing, to say the least, to spend considerable sums of money and time on systems that do not perform a useful function. Many of these mistakes can be avoided if the function of the system is carefully specified from the beginning. Criteria should be developed that will measure the effectiveness of the system.

AUTOMATIC TRAFFIC OPERATIONS AND MAINTENANCE IN THE PORT OF NEW YORK AUTHORITY

Alan T. Gonseth, The Port of New York Authority

The Port Authority is a bi-state agency created by compact between the states of New York and New Jersey in 1921. The organization has two primary functions: to promote and protect trade within the port district; and to build, develop, and operate terminal and transportation facilities within the port district. The Port Authority has grown to where it now operates 23 facilities that cost more than \$2.5 billion to construct. These facilities include four airports, two heliports, four bridges, two tunnels, two bus terminals, two truck terminals, two freight terminals, four marine seaports, one railroad, and the World Trade Center.

The complex roadway and highway systems, either within these facilities or contiguous to them, are prime candidates for automatic traffic operations because of the unusually heavy traffic demands and high construction costs associated with them. Improved traffic operations and maintenance through automatic means can provide high dividends in public service in these congested areas.

AUTOMATIC TRAFFIC OPERATIONS

The tunnels and bridges that are operated by the Port Authority are toll facilities. Because there are significant operating costs associated with toll collection, various types of automated tolls have been implemented or are under study to improve patron service at less cost. These programs include such things as automatic computer recording and summarizing each toll collector's transactions and performance. The automatic collection of cash is a proven toll-road technique; however, the Port Authority has been testing the application of automatic vehicle identification and magnetic cards as an automatic toll operation. Apart from the tolls operation, the direct automatic control of traffic has been implemented in the Holland and Lincoln Tunnels; an automatic traffic-control system has been installed at Kennedy International Airport, and another is in progress as part of the new Newark Airport ground-transportation plan. A Traffic Measurement System (TMS) has recently been installed at all tunnel and bridge facilities to automatically give instantaneous operational information.

Tunnel Traffic Control System

The forerunner of all freeway surveillance systems was the basic tunnel traffic control system (TTCS) project. In 1959, after a year of preliminary theoretical research, gaps were manually inserted in the streams of traffic entering the Holland Tunnel. This crude manner of metering traffic eventually proved the concept that vehicular throughput is improved by maintaining good speed and density characteristics. Since then, the development of the automatic flow-control system has been reported at a number of Highway Research Board and other technical meetings.

At the present time, final work is being completed on the 5-tube, or 10-lane, control system that uses 140 vehicle detectors, 3 mini-computers, and 12 changeable-message signs to measure and control the traffic automatically. The system is augmented by closed-circuit television, tunnel radio communication, and a rapid catwalk transportation system.

The detectors constantly measure actual, not calculated, speed and volume at a point and measure the actual density or inventory vehicles over a zone. Computer logic can predict imminent deterioration in the traffic stream and can call for the appropriate degree of control that will ensure restoration of optimum flow. The sensitivity of the system is such that extremely accurate measurements of the traffic-stream characteristics are required, and that is the backbone of the density-oriented logic system. Controls currently used are changeable-message signs at the tunnel portals that read either PAUSE HERE THEN GO or STOP. The former is used in conjunction with a flashing amber signal unless there is an unusual circumstance that requires the latter message in order to return traffic to a fluid flow.

The system also detects stoppages or other discontinuities and alerts the operating police who can confirm the trouble source by closed-circuit television and radio for emergency response.

TTCS has improved peak-hour traffic flow by approximately 10 percent, which, when applied to 10 traffic lanes, is equal to the construction of an additional tunnel lane. In 1957, the construction of the 2-lane third tube of the Lincoln Tunnel cost more than \$90 million, which would certainly cost more than double that if it were built today. However, the TTCS program was actually installed in four tubes at a cost of \$3.4 million, and the automation aspects greatly improved the operation and reduced enough labor costs to pay for the project in 8 years.

Therefore, TTCS has provided greater capacity at less annual cost while also providing improved communications and operational features to the tunnel management.

Traffic Measurement System

For years Port Authority staff discussed the need for developing a system that would automatically classify vehicles. When the Tunnels and Bridges Department adopted a one-way tolls policy (pay double toll going east and travel free going west), it was recognized that half of the vehicle classification data would be lost. Annual, monthly, weekly, and certain weekday data could be approximated by using appropriate eastbound data. However, valuable weekend, peak-period, and hourly data would be lost. Consequently, an automatic system was developed to classify traffic and provide operating personnel with constantly updated information as well as alert planners to changes in trends.

The system basically measures the speed of a vehicle over a pair of detectors and the blockage time of one of the detectors. From this the length of the vehicle can be determined within an inch. A look-up table then provides the classification.

Kennedy International Airport Traffic System

Kennedy International Airport can be thought of as five separate airports with several routes connecting all areas. In the early years of its operations a simple crosswalk was sufficient to move air travelers from the terminals to many of the parking areas in the central terminal areas (CTA). The increase in the number of air passengers resulted in increased ground traffic; pedestrian conflicts and traffic delay resulted. The long-range solution, to be implemented in the near future, is multilevel parking with direct overhead connections to the terminals to eliminate all conflicts. An intermediate step of installing pedestrian bridges or tunnels was rejected because people refuse to use them unless there is no alternative. Another intermediate solution considered was the installation of a traffic-responsive signalized crosswalk system. Such a system was put into operation at the airport in September 1967. The analog system calculates traffic stream density at strategic locations on the CTA roadway network and automatically adjusts signal cycle lengths based on the traffic density and pedestrian pushbutton demands. In addition, a diversionary signing system that recommends alternate routes within the CTA is produced by the same sensing devices.

Pedestrian crosswalk accidents decreased 22 percent overall and 55 percent during peak hours despite a 50 percent increase in both vehicular and pedestrian traffic. The overall vehicular accident rate also decreased about 7 percent whereas travel times remained the same.

MAINTENANCE

Maintenance in the Port Authority is performed by different groups. Certain jobs are done by contract with outside organizations, other major jobs are done by a special unit called Central Maintenance Services, and the remaining work is done by facility employees.

Contract Maintenance

Special recurring maintenance work, such as computer maintenance, is usually done by contract. Similarly, major nonrecurring jobs such as bridge-deck replacements, sandblasting, and buried standpipe-system inspection are also done by contract as are other jobs that can be handled within the organization but where time or manpower does not permit.

Central Maintenance Services

Central Maintenance Services does the recurring major maintenance jobs at the various Port Authority facilities. This work includes such things as pavement patching, electromechanical equipment maintenance, and bridge painting.

Facility Maintenance Unit

The facility staff performs the daily operational maintenance. All maintenance jobs are classified as either routine or nonroutine. As their labels indicate routine jobs are ones that can be predicted in advance and for which a logical cycle can be planned. A nonroutine job is, of course, one that does not occur regularly.

A roster has been developed for all routine jobs. A work-order number is assigned to each job as is other pertinent information such as skill required, accounting code, description and locations, frequency per year, and biweekly periods scheduled. A daily work sheet can be automatically made in advance for supervisory planning purposes, and then actual performance can be added for later review on a day-to-day basis. With these data in computer storage and employee time cards geared for keypunching, it is obviously easy to produce monthly, quarterly, and annual reports on variances from schedule, program costs, and efficiencies.

The nonroutine jobs utilize approximately 40 percent of the crew's time and are requested as they arise. Prefix code numbers describe the urgency as immediate, within 24 hours, or whenever convenient.

Obviously the judicious scheduling of manpower must be tempered by the judgment of the supervisory staff. A 3- or 4-day snowstorm disrupts any rigid schedule such that adjustments have to be made. The variations from schedule can be identified and explained at a later date.

THE LOS ANGELES 42-MILE SURVEILLANCE AND CONTROL PROJECT

Alvord C. Estep, California Division of Highways

For many years, the need for better communication between users of the California highway system and the system itself has been recognized. The 5-phased surveillance and control project in the Los Angeles area is considered to be a major step toward meeting that need.

The project is an experimental effort to test and evaluate a freeway surveillance and control system that could eventually become a standard installation on most of the urban freeways. The project will include four basic phases: (a) an electronic surveillance system with traffic-responsive ramp control, (b) early detection and rapid removal of unusual incidents, (c) real-time warning and information, and (d) service for stranded motorists. In addition, a major air monitoring experiment is being coordinated with the project. This experiment will determine the amount and distribution of exhaust emissions on and adjacent to the freeway. It will then attempt to relate the level of emissions to freeway geometrics and operating conditions.

The Federal Highway Administration (FHWA) is participating in the cost of the electronic surveillance system and may participate in the construction of changeable-message signs in relation to the real-time warning and information system. In addition, the FHWA is participating in the evaluation of most phases of the project. The second phase of the project (early detection and rapid removal of unusual incidents) has received a \$2 million grant from the National Highway Traffic Safety Administration.

The project is located in the center of the Los Angeles urban area on three of the most heavily traveled freeways in the world: the Santa Monica, San Diego, and Harbor Freeways. The project is 42 miles in length and has within its boundaries 56 freeway interchanges. This 42-mile loop of freeways serves downtown Los Angeles, the University of Southern California, the Los Angeles campus of the University of California, and the Los Angeles International Airport.

The primary purpose of this project is to see whether we can reduce delay, accidents, and aggravation caused by nonrecurrent (incident-caused) congestion. The first objective is to test and evaluate various techniques that (a) detect incidents and remove the cause and (b) communicate information to drivers. The second objective is to integrate those techniques showing greatest promise into an effective operating system.

Surveillance systems are often erroneously thought of as exotic ramp controllers. Although ramp control and freeway surveillance are complementary, they are actually two separate concepts. Surveillance and control attempt to reduce nonrecurrent congestion, whereas ramp control is a technique used to reduce or eliminate recurrent (geometric bottleneck) congestion. The surveillance computer is used to drive the ramp control simply because of its availability.

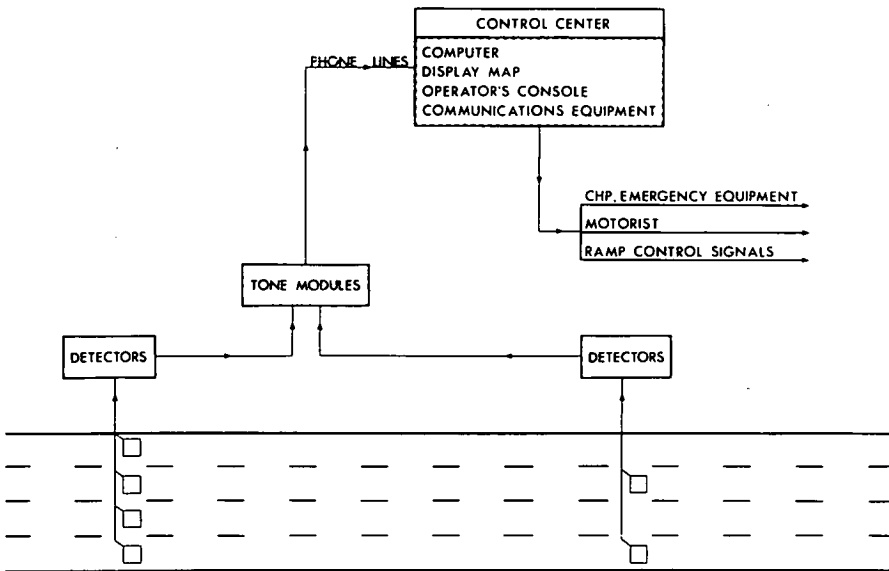
I consider ramp control to be beyond the experimental stage. Many ramp-control projects are being planned and installed in California without elaborate surveillance. We are, however, beginning to realize that some surveillance is necessary to keep operating personnel informed of ramp-control efficiency. This same philosophy also applies to traffic signals on conventional arterial highways.

ELECTRONIC SURVEILLANCE AND RAMP CONTROL

Surveillance and Incident Detection

The electronic surveillance system (Fig. 1) will be composed of (a) about 700 loop

Figure 1. Basic surveillance process.



detectors, (b) telemetering equipment to transmit traffic data over telephone lines, and (c) a control center. The control center will have (a) a digital computer to log incoming data and to help make decisions, (b) a display or status map of the surveillance project showing the status of traffic on the freeway at all times, (c) other display equipment including status lights for all metered ramps, computer output devices, a television screen, and (d) communication equipment. The control center will be operated by an interdisciplinary team composed of traffic engineers, maintenance personnel, and highway patrol officers.

The freeway traffic detectors will provide traffic data in the form of volume and occupancy. Occupancy is a measure of "how occupied" the freeway is and can be compared to density. These data will be processed by the computer into useful information for decision-making.

The traffic sensors will be placed in each of the freeway lanes at approximately $\frac{1}{2}$ -mile intervals. At some of these locations, traffic sensors in all lanes will be active; these locations are called full count detector stations and will be located at approximately 3-mile intervals. At other locations, only two traffic sensors will be active; these locations are called sample detector stations and will be located between the full count detector stations.

A vehicle on the freeway is detected by the traffic sensor, and a signal is transmitted to the digital computer in the control center via voice-grade telephone lines. The computer then converts this information into volume (vehicle counts) and percentage of occupancy data for each active traffic sensor in the freeway pavement. Using these parameters and programmed logic, the computer performs several functions, including the following real-time functions:

1. Update display map;
2. Detect incidents affecting traffic flow on freeway;
3. Drive ramp-control signals at some ramps; and
4. Calculate delay on the system in vehicle-minutes.

Volume and occupancy are the basic data for this system. The sample time can be 20 or 30 sec (as determined by the operator). Both flow rate and occupancy are smoothed by averaging the most current three samples; i.e., they are 1-min averages updated every 20 sec.

Volume is the total number of vehicles passing the detector station for a specific time period. For a full count detector station, where traffic sensors in every lane are active, the volume is the actual number of vehicles counted. Occupancy is calculated every 20 or 30 sec (depending on the chosen sample time) for each individual active sensor and then averaged over the number of active sensors at that detector station. A running average of the detector station occupancy is calculated and updated at every sample time.

The 42-mile freeway system is schematically displayed on a map display panel. Status lights on the map indicate the quality of traffic on the system. The status light indications are controlled by the computer according to the occupancy level at each detector station. One of four colored light indications can be displayed at any one time. The colors displayed are green, yellow, and red. The red is also capable of being flashed. A green light indicates free flow conditions with no congestion; a yellow light indicates traffic is moving with some congestion; and a red light indicates stop-and-go conditions. A flashing red light indicates an incident at that detector station. The display map is updated by the computer at the end of every sample time.

The detection of incidents is handled by the computer utilizing the computed occupancy data at each detector station. The incident detection logic is based on a comparison of occupancy values at each adjacent detector station. When part of the freeway is blocked (such as in the case of an accident), the occupancy upstream of the incident increases and the occupancy downstream of the incident decreases.

If the difference in occupancy produces a value greater than some constant, K_1 , a bottleneck condition exists; however, it has not necessarily been caused by an incident. The occupancy of the downstream detector station is then compared with the previous sampling (20 or 30 sec prior). If that difference produces a value greater than some constant, K_2 , then an incident has occurred somewhere between the two detector stations.

In a typical geometric bottleneck, occupancy upstream of the bottleneck is higher than occupancy downstream. The occupancy downstream of the bottleneck remains essentially constant. With the occurrence of an incident that reduces the capacity of the freeway, downstream occupancy not only is lower than upstream occupancy but also rapidly decreases from the occupancy value of the previous sampling time.

Traffic-Responsive Ramp Control

Currently there are three successful ramp-control projects in operation in the Los Angeles area. All are simple fixed-time (i.e., preset rates) systems that meter traffic onto the freeway by using historical data. The preset rates are based on average conditions for various times of day. During the course of the project, several ramp-control projects (existing and proposed) within the limits of the surveillance project will be made traffic-responsive (metering rates and control decisions based on actual traffic) and will be controlled by the computer. A determination will be made of the marginal benefits of traffic-responsive centralized computer control.

Construction of the surveillance system is currently in progress at a cost of \$1.3 million. Work is proceeding on both field and office installations, and completion is expected in the summer of 1971. This installation is the key element in the entire experimental project.

EARLY DETECTION AND RAPID REMOVAL OF UNUSUAL INCIDENTS

The early location and rapid removal of freeway incidents remains one of the most promising areas for freeway operation improvement. Techniques to be evaluated in this are (a) a computer logic for rapidly detecting unusual incidents, (b) the use of aircraft surveillance and live closed-circuit television transmission from an aircraft, and (c) the use of specially equipped state-owned tow trucks to remove unusual incidents completely from the freeway.

The computer logic is a special computer program that provides an alarm for the control center team. The helicopter-television system is intended to provide additional information as required for control team decisions. This phase of our system is being funded under a \$2 million grant from the National Highway Safety Bureau. The

helicopter-television system (operated by the California Highway Patrol) and tow trucks (operated by the California Division of Highways) will begin testing and evaluation during the latter part of 1971.

REAL-TIME WARNING AND INFORMATION

Most of the information that a motorist needs about the road ahead is provided by permanent freeway signing. There has been much discussion of providing motorists with current information on traffic conditions (i.e., real-time information); however, few field tests have been made. In this general area, the techniques to be tested and evaluated are (a) improvement of commercial radio traffic advisories, (b) roadside radio (i.e., limited-range broadcast through the normal AM radio), and (c) freeway-size changeable-message signs. Each of these communication modes offers unique opportunities, and the right combination of the three should provide a very effective system.

Contacts for the commercial radio traffic advisories have been made with the Southern California Broadcasters Association and major radio stations in the Los Angeles area. All have promised cooperation. An application for operation of a 16-mile roadside radio transmitting system has been filed with the Federal Communications Commission. A contract with the Institute of Traffic and Transportation Engineering of the University of California, Los Angeles, will determine the type of messages to be used with the changeable-message signs and roadside radio. A pilot project to test and evaluate these messages on a single-matrix sign is currently being planned for one ramp on the inbound Hollywood Freeway Ramp Control Project. Dates for the beginning of testing and evaluation are (a) commercial radio, January 1972; (b) roadside radio, January 1972; and (c) changeable-message signs, July 1972.

SERVICE FOR STRANDED MOTORISTS

As part of the surveillance project, we are evaluating the existing urban freeway telephone system and other means of providing service for stranded motorists. One technique that we will be looking at is the service patrol. Testing and evaluation of the use of service patrol vehicles to assist stranded motorists will begin in July 1972.

FREEWAY AIR MONITORING EXPERIMENT

The purpose of this phase will be to determine the amount and distribution of vehicle-generated air contaminants both on and adjacent to the freeway. The project will relate contaminant levels to freeway geometrics (e.g., grades and location) and to freeway operating conditions (e.g., free moving and stop-and-go). Both stationary and portable equipment (mobile labs) will be used to collect samples and other data. The design of mobile labs is under way, and sites for monitoring have been selected. It is hoped that testing and evaluation will begin during the fall of 1971.

MAINTENANCE MANAGEMENT IN OREGON

Tom Edwards, Oregon Department of Transportation

When the then Oregon State Highway Division was organized in 1917, the accounting record system was set up in such a manner that only minor changes have been necessary during the past 54 years. The system has never required major revision. The basic management program is one of administrative staff, regional, and district control.

The last revision to geographic regions and districts (in 1968) was made to conform to a district planning concept covering all phases of state government, both planning and administration. Again, the district boundaries required only minor adjustment.

The state is now divided into five regions. The regions are further subdivided into districts. This basic control pattern has been further broken down by areas. Each county has a number, the numbers progressing consecutively through the alphabetical listing of the counties. As the highway system evolved, each highway was given a special record number, not connected with any federal, state, or map route number. Each of these highways was mileposted. Within each of these countries, control sections were established on each highway.

The control section numbers on primary highways start with 1; on secondary highways they start with 61. In assigning maintenance and minor betterment costs to a particular section of highway, we use a numerical prefix. The control section number is preceded by a number indicating the type of work. Number 12 is used for minor betterment, and number 44 is used for regular maintenance. Each item of work is further identified with a suffix that denotes the class of work involved. These items are broken down into nine major classes of work. With this basic code, it is then simple to indicate on documents the proper recording of any item of work.

The coding system provides for directly charging all labor and materials to the highway section to which it was applied. The payroll system and the payroll report system require that the function numbers for each hour of labor be correctly affixed. The same is true of materials. Each item that is purchased is paid for only after the proper accounting number has been affixed to the invoice. This system is used whether the item being purchased is a 5-cent bag of nails or sanding material worth \$250,000.

Once labor and material costs are accounted for, the proper distribution of equipment costs must be determined. As stated earlier, each piece of equipment purchased is given a number that indicates year, model, and type of equipment.

The vehicle number is indicated on the invoice for gasoline, tires, maintenance labor, or any other item that is purchased for that piece of equipment on the vehicle. The initial cost is also recorded. Thus, the purchase cost and the maintenance of the equipment are charged against the individual equipment. This equipment and its use must be accounted for by a monthly equipment report showing sections on which it was used. Each fleet is given a fleet code number, and a daily rental rate is established for each vehicle.

With this basic system, an accurate accounting can be made of the labor and materials and equipment going into each predetermined section of the highway.

Let us now turn to control. The total budget for maintenance and planned activities is established by administrative judgment. The judgment, particularly with respect to general maintenance, becomes a question of policy: Do we wish a more concentrated effort on certain items of maintenance such as roadside cleanup, or do we want increased snow and ice control? After those judgments have been made, a budget is prepared based on manpower, equipment, and material needed to sustain the program

at the desired level. The budget is then submitted to the proper authorities (in our case the state legislature) for approval.

After approval, the budget is reworked by the maintenance staff and allocated to the regions and in turn subdivided among districts based on four factors: (a) vehicle ton-miles, (b) lane-miles of highway, (c) experience, and (d) snow-removal cost. Snow-removal funds are allocated first to the regions and districts based on past experience. The remaining funds are then subdivided by a formula using 50 percent for vehicle ton-miles, 25 percent for lane-miles of highway, and 25 percent by experience cost over the past 3 years. The experience factor covers the allocation of additional moneys to sections subject to slides or lesser moneys to sections that have neither brush-cutting nor slides. Each district engineer then becomes responsible for his budget to the regional engineer; each regional engineer in turn is responsible to the central staff for the budget for his region.

The central staff must then provide guidance and control. For control, the staff uses a bi-monthly report covering expenditures to date, budget, and percentage spent. This report is normally furnished within 15 days after the close of the period. Another report covers the same time period and further breaks down the expenditures into nine maintenance categories showing the percentage of that district's total budget that has been spent on the specific items in question. Both reports show the total amount of effort being expended by the district and where the effort is being applied. A third report further pinpoints the area of effort. The specific jobs on each specific control section are detailed in this report, and the particular cost of any one piece of work can be determined at any time. We feel that constant surveillance of these reports at district, region, and staff levels has provided a method of control to indicate the precise location and amount of maintenance effort being expended.

In addition to the budget reports, a monthly summary of the manpower assignments for each crew is supplied to the maintenance section. Each crew has a number permanently assigned to it and a permanent complement of personnel that may vary from summer to winter. The report indicates the number of positions filled at any time. These positions are the permanent civil service positions, and no district or regional engineer has the authority to exceed these complements without approval by the Position Review Board. He does have the authority in case of emergency to hire personnel as required under an emergency or on a temporary basis. This report also lists the name, retirement number, position number, and social security number of every man on the payroll.

Another payroll report is made basically for management. It lists, by various classes of work, the number of employees on the payroll for the past month during the current year and also the preceding year, the number on the payroll for the immediate month, and the amount of regular and overtime work. Another report pinpoints the overtime expended by various crews and by various men.

The several reports used for equipment control are as follows:

1. A listing by vehicle type of the number of units of each model owned;
2. A listing of the crew number, location, and number of vehicles of each type assigned to that crew;
3. A summary listing by types of vehicles of crew, individual vehicles assigned to that crew, mileage of hours for that vehicle, and number of shifts the car was used, cost per mile both for the preceding month and for the past 12 months, total mileage that the equipment has been operated throughout its life, and total cost of maintenance and upkeep;
4. Status of all equipment by fleet including miles per month, shifts, total rental income, and total cost of the equipment both for the 12-month period and for the entire life of the equipment. (The report provides the equipment superintendent and his staff sufficient data to analyze equipment fleet utilization and cost both by fleet and by manufacturer, identifies by each individual unit equipment requiring major maintenance, and recommends appropriate action such as sell or repair);
5. A listing of maintenance costs only, broken down into nine categories: preventive maintenance costs, tires and tubes, engine, power train, electric components, air and hydraulic components, axle and suspension gear, body and chassis, and miscellaneous

(proper analysis of this report is an aid in the preparation of the specifications for future equipment acquisition and permits identification of components that have proved to be costly); and

6. A listing that summarizes throughout the total life of each piece of equipment the acquisition, depreciation, maintenance and operating costs, sale price received, total rental receipts, and total ownership cost.

PART V

TRANSPORTATION INFORMATION PLANNING SYSTEMS

PLANNING INFORMATION SYSTEMS: AN OVERVIEW

Robert E. Barraclough, Information Systems Consultant

Planning information systems are integral parts of planning processes. These systems consist of data, machines, and sets of manual-machine procedures for developing, managing, and analyzing data, yet the key to designing and implementing them is the planning processes that they must serve. This is not to say that planning processes themselves can be defined abstractly without regard to the types of data that are available (or can be collected) or the analysis procedures that are available (or can be developed). It is to say that it is futile to design and develop planning information systems without close attention to the planning processes to be served. Planning information systems must be deeply rooted in the planning processes, which must be developed with careful regard to available (or potentially available) data, machines, and procedures.

Functions to be served by transportation planning information systems are long-range transportation planning, short-range transportation planning, continuing transportation planning, and service to staff and other agencies. Initially, there is an emphasis on preparation of long- and short-range transportation plans, but eventually there is a need for continuing planning processes as well as a need to serve the staffs of planning and outside agencies. Inevitably, special projects are proposed that necessitate the preparation of special reports. Planning information systems must be capable of handling these special needs without upsetting the normal work flow; this should not be overlooked in the design of planning information systems.

The procedures required to serve the transportation planning processes are data collection, data management, and analysis including forecasting, simulation, and evaluation. It is important also to provide for procedures that relate to research activities—research on the usefulness of the data being obtained for planning purposes, the determination of new data requirements, and the development of new procedures.

The data needs for transportation planning processes are land use activities, person and goods movements, and transportation facilities and terminals. Information is needed on the objects and object groups that are the subject of concern in the planning process, on characteristics of these objects and object groups that will aid in determining future demands and supply requirements, and on characteristics that will aid in evaluating alternatives for meeting future supply requirements. The information on the objects, object groups, and characteristics must be identified in terms of their places in time and space. Also, special information is often needed for special projects and research activities—information that is not required for the normal planning processes.

PLANNING PROCESSES

There are many different types of planning processes. Three criteria—subject matter, geographic area, and time horizon—may be used to categorize these processes. In regard to the time horizon, there are long- and short-range and continuing planning processes. The geographic areas of concern are (a) the entire country, as in national planning; (b) large areas of the country, as in regional or corridor planning (for example, the Northeast Corridor Transportation Project); (c) states, as in statewide planning; (d) metropolitan areas, as in metropolitan planning; and (e) small areas within metropolitan areas, as in local planning.

Each of these types of planning is concerned with serving the needs of the population of some particular geographic area. The subject area of concern can be transportation,

health, education, environment, recreation, social development, economic development, or land development.

In each of these areas, planning is concerned with serving some aspect of the total needs of a given population. Because there are so many different types of planning, it is important to provide coordination among them. Long- and short-range planning should be related, as should metropolitan and statewide planning and land development and transportation planning. An important element in each planning process is the provision that it can be related to other planning processes.

The specific subject area of concern here is transportation, but there are many types of transportation planning, for example, transit, rail, air, highway, TOPICS, statewide, and urban. Each of these types of transportation planning has unique subject areas of concern, geographic areas, and time horizons.

For each type of transportation planning, some objectives will be different, and some objectives will generally apply to all types of transportation planning. The overall objective in most cases is to determine recommended future requirements for transportation facilities. More specifically, the objective is to determine the following:

1. Recommended levels of investment in transportation facilities;
2. The division of investment between the major modes of transportation for movement of people and goods;
3. The location and size of transportation facilities; and
4. The sequence and timing of investments.

These objectives are generally applicable not only to different types of transportation planning but also (with appropriate modification) to different types of planning in other subject areas such as health planning. This parallelism of objectives provides a useful basis for structuring coordination among the different types of planning so as to make it easy for government, industry, and the public to choose between alternative proposals for investments in a large number of different fields, for example, to choose between investment in a new highway as opposed to a new hospital.

For a more specific idea of the planning processes for which transportation planning information systems are designed, let us consider the long-range urban transportation planning process. In this process, current and time-series data are used as follows (1):

1. Forecast future total metropolitan population, employment, and other economic factors;
2. Forecast future distribution of land uses and trips throughout the metropolitan area;
3. Split future trips among different modes;
4. Assign future trips to proposed future networks of transportation facilities (plan testing);
5. Evaluate performance of alternative proposed future networks of transportation facilities; and
6. Determine a recommended plan for future transportation facilities together with proposals for timing and sequence of investments.

REQUIRED PROCEDURES

Once the planning process has been defined, it is necessary to design and develop the manual-machine procedures required for collection, management, analysis, graphic display, and tabulation of data. For data collection, a wide variety of procedures are required for performing field surveys, sampling, processing secondary data, geocoding, general coding and file building, logical checking, editing, and summarization. The procedures for geocoding and general coding must be carefully developed to ensure flexibility in data manipulation and compatibility among the different sets of data so that they can be easily related to one another. Also, they must be based on a set of uniform definitions for data elements.

For data management, standard routines are essential for documentation of data files, storage and retrieval of data, transformation of data, development of working files, and storage of files that are not currently being used but may be needed in the future. For

analysis, routines are needed for performing various statistical analyses, forecasting population and economic growth, forecasting distributions of land uses and trips, simulating the flows of vehicles through transportation networks, simulating transfers of persons and goods at terminals, and evaluating the performance of proposed transportation facilities in terms of volumes carried, user costs, nonuser costs, and impacts generally (for example, in terms of effects on future population and industrial distributions, future land use patterns, and future environment). The simulation procedures should provide not only for handling flows through networks for individual modes but also for handling flows through multimodal networks. In addition, standard routines are required for tabulating and displaying data. These should be highly flexible, rapid, economic, and easy to use so that it is a simple matter to produce rapidly a wide variety of tables, maps, and charts.

Planners, engineers, and others who know the planning problems should be able to use the procedures with minimal or no help from systems analysts and programmers. Sometimes programmers and systems analysts are attached to planning, engineering, and analysis units to narrow the communications gap that often exists between those who know the problems and those who know how to use the computer. This is a good short-term solution, but the procedures should be designed such that the real users have direct access to the planning information system.

With the use of systems that have remote access terminals, this approach becomes even more important. Eventually, the proper role for systems analysts and programmers attached to a data center is to develop and operate a system that has all the required procedures and sufficient capacity. Their role should be similar to that of telephone engineers who provide a system that users have direct access to such as the expanded direct-long-distance dialing systems that we now have in many parts of the country. Also, the procedures should eventually be integrated into a single system that permits easy use of the outputs from one part of the system as the inputs to another.

There are innovations that will likely occur as transportation planning information systems are developed. For example, it appears likely that in the near future we will be able to plan sophisticated man-machine-mapping transportation planning systems similar to those now being developed for highway design. The transportation planner calls for a map, sees it displayed, draws proposals, sees future consequences, and receives an evaluation of these proposals. Then he repeats the process several times, altering his proposals each time, until he obtains the best plan.

Historically, transportation planning has been limited to the use of maps. An interactive man-machine-mapping transportation planning system would have the advantages of older transportation planning methods plus the advantages of the newer methods. There may even be effective methods in the near future for rapid participation of groups of professionals or citizens in the planning process. For example, experiments recently initiated under the name MINERVA (conducted by the Center for Policy Research, Columbia University) are directed at rapid polling by telephone-television-computer hookups. Wherever feasible, planning information systems should be designed such that transition to future systems does not present a problem.

DATA NEEDS

Data needs vary considerably depending on the particular planning processes for which the planning information systems are designed. For example, short-range transportation planning processes usually require more detailed data in terms of subject matter and geographic level than do long-range planning processes. A similar distinction can be made in regard to the data needs for urban as opposed to statewide and national planning processes. It is possible, however, to distinguish broad types of data needs. Figure 1 (2) shows three dimensions of data needs: activity, mode, and geography. A time dimension should also be included.

The same general classes of data needs referred to earlier are found in the activity dimension. First, there are measures of the sizes and locations of activities that give rise to the flows of people and goods, i.e., measures of critical characteristics of residential, manufacturing, retailing, wholesaling, educational, social, and recreational

activities. Second, there are measures of the sizes and locations of the average daily, weekly, or annual flows of people, goods, and vehicles among the activities; the characteristics of the persons involved help explain the sizes of the flows. Third, there are measures of the sizes and locations of the channels or networks of transportation facilities and terminals that carry the flows of people and goods (their usage, level of service, and other characteristics of the facilities including accidents).

The mode dimension is of particular concern in channel and flow data. It is essential to identify the separate modes used in people and goods movements in such a way that separate modal flow, multimodal flows, and intermodal transfers can be easily determined. It is essential also to describe the networks of transportation facilities and terminals in such a way that flows involving usage of an individual modal network as well as flows involving usage of multimodal networks can be simulated.

It is convenient to focus separately on each of the three elements of the geographic dimension: urban, interurban, and international. Different types of flows and networks are involved in each case. In urban areas, there are large volumes of short trips, whereas interurban and international trips are longer and fewer in number. Again, we should be able to relate easily the data for these separate geographic areas.

In discussing the required procedures for planning information systems, we referred to the need to work toward the development of integrated procedures. There should be a parallel concern in the data area for the development of integrated compatible data sets. The sets must be viewed as integral parts of a single whole, and they must be structured such that they can easily be used with one another. As indicated earlier, the necessary compatibility among the different data sets is achieved through uniformity in definitions for data elements and in coding schemes, particularly those for geographic coding.

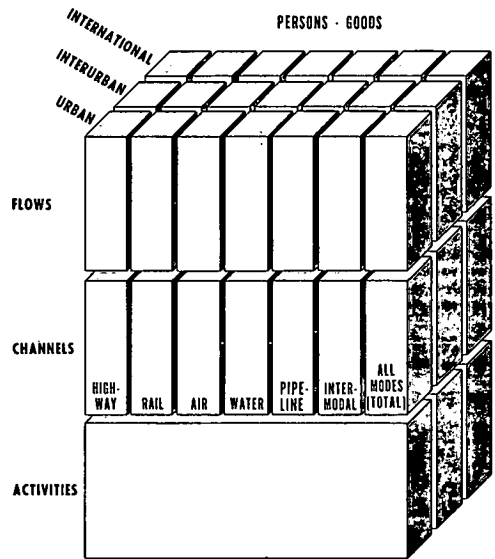
The need for long lead times to obtain and process data is important. Based on past experience in the urban field, periods of 2 to 3 years appear to be normal; this increases the period required for development of initial tested plans to 4 or 5 years. Data are obtained during the 2- to 3-year time periods in the urban field only with considerable concentrated effort. It is essential to establish individual data programs early with sufficient resources and strong management to avoid long delays in planning processes, and, wherever possible, these should be established from the outset to facilitate the later development of continuing data.

Every effort should be made to obtain all possible data and data processing tools by cooperative arrangements so that it is not necessary for each separate planning agency to start from scratch to produce all data and processing tools on an ad hoc individual basis. Through cooperation at urban, state, and national levels, it is possible to obtain some of the required data and data processing tools from and through agencies such as the U. S. Bureau of the Census and the U. S. Department of Transportation.

CONCLUSIONS

Computers and computerized procedures have been used extensively in transportation planning. The most extensive applications have been at the metropolitan level where long-range transportation planning processes have been developed and implemented for

Figure 1. Transportation data structure.



more than 200 metropolitan areas during a period of about 15 years. More recently at this level, attention has been given to development of information systems to support continuing transportation planning activities. Accomplishments at state and national levels so far have not matched those at metropolitan levels; the period involved here has been shorter, about 3 years.

Future applications of computers and computerized procedures to transportation planning will be substantially increased if apparent commitments to planning activities are realized. We appear to be committed to (a) continuing urban transportation planning for all metropolitan areas, (b) initial and continuing statewide transportation planning for all states, and (c) initial and continuing transportation planning at the national level. This type of planning activity is essential to support effective policy-making and program development at all levels of government, not only in the area of transportation but also in other areas such as land development. Within the transportation field, this planning activity is essential for effective evaluation of alternative proposals for investments in various modes of transportation at all levels in terms of performance of the transportation systems; costs and benefits to users and nonusers; and impacts on population and industrial distributions, land development, and the environment in general.

Present allocations of manpower and money will have to be increased severalfold if we want to achieve, within a reasonable time, the levels of planning activity we seem to be committed to. At present, there is a disconcerting vagueness about these activities. The following steps should be taken to clarify our plans.

1. Define objectives for transportation planning activity at all levels of government including planning processes;
2. Establish target dates for accomplishment of milestones in these activities; and
3. Provide funding at appropriate levels to implement the planning programs.

There have been claims that transportation planning costs are too high. Based on experience at the metropolitan level, these claims appear to be unfounded. The study referred to earlier (1) found that metropolitan transportation planning costs have averaged less than 1 percent of the capital costs of the recommended plans. Costs for initial and continuing planning at statewide and national levels and continuing planning at metropolitan levels are not likely to exceed this 1 percent figure.

To implement the foregoing planning programs will require organizational changes, particularly at the state level. For example, many states still do not have departments of transportation, while others do not have planning units. In addition, there should be mechanisms for coordination of transportation planning activities with other planning activities within each unit of government. Also, there is a need for federal-state-urban cooperative arrangements for a number of purposes. For example, there are data that are required at both state and national levels that can only be developed economically at the national level. There is a need for development of uniform computerized procedures that can serve all states (but that allow variation from state to state in planning program content and emphasis).

Although there is a need for emphasis on the development of improved computerized procedures for transportation planning (particularly the development of integrated packages and systems), greater emphasis should be placed on the development of the necessary data bases. This will prove to be a formidable obstacle in establishment of effective and timely planning processes. Every effort should be made to research and develop new methods that are less costly and time-consuming and that will yield continuing data. However, even with the best possible methods a long lead time will still be required to obtain and process essential data because the volume of required data is so great and the processing requirements are so substantial. To realize our planning information systems within a reasonable time, we must put great emphasis on defining the planning processes and procedures in sufficient detail for determining data needs. (Previous experience at the metropolitan level shows that this is possible.) Then we must try to obtain the needed data as quickly as possible.

Finally, more attention should be given to determining the costs and benefits of planning information systems, or even of planning processes. One method is to develop an interim plan early in the planning process before the computerized planning information

system is established. The merits of this plan can then be compared with those of a final plan produced after the computerized system is established. Something like this was done by the Tri-State Transportation Planning Commission in preparing long-range transportation plans for the Connecticut-New Jersey-New York metropolitan area. More work along these lines should be done so that we can establish clearly the benefits of our more sophisticated approaches to planning processes.

ACKNOWLEDGMENT

I wish to acknowledge my indebtedness to the many people whose ideas have contributed to the present study. Particular thanks are due to John Hamburg of Creighton, Hamburg, Inc., for various ideas on urban and statewide planning information systems.

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DEVELOPMENT OF A DATA BASE FOR BIENNIAL NATIONAL TRANSPORTATION NEEDS REPORTING

Alan E. Pisarski, U. S. Department of Transportation

For the 1972 study, the National Transportation Needs Study made heavy demands on the existing data bases and planning processes of the states. The time frame of the Biennial Needs Study made it mandatory that the responses be keyed to existing processes. Very little primary data collection was possible. Thus, states that had extensive statewide planning processes found that they could gather a great amount of the required data from their ongoing process. States that did not have such a process found the task much more difficult. There is a need for additional data, separate from the states' systems, to support the overall analytical and reporting process concerning transportation needs. Some of these required data, such as information on industry's investment plans, are being collected. Other kinds of data with longer lead-time requirements are under development but are not yet available.

In short, in 1972 the data flow has been something of a one-way street with data moving from the states to the federal level primarily. We can help to redress this imbalance by returning to each state its own data and the data from the other states in an effectively usable form. Tabulations from the states' returns and special tabulations of urban areas and states stratified by type will be available in computer tape, microfilm, and printed form.

The lead times are great for the development of the kinds of data and system we require. We must begin now, even before the 1972 returns are in, to plan for 1974 and beyond. What kinds of realistic goals can we establish for 1974? Certainly a major goal is to make the biennial reporting a natural by-product of the existing process. In addition, I think we can establish the following goals:

1. Add transportation systems performance measures to the data set reported;
2. Provide the states extensive input data collected at the national level;
3. Provide better information system support to the states; and
4. Add more time and money to support the process.

If the Biennial Needs Study is to be a viable and effective process, it must incorporate the capacity to describe the quality of performance of all modes of the national transportation system. It must include an ongoing performance indicator system including such measures as average line-haul speeds, load factors, and measures of schedule adherence. In order to obtain some of these measures, the U. S. Department of Transportation has been working with the U. S. Bureau of the Census to make the 1970 census data more effective for transportation planning. One product of that effort is the standard tabulation of the journey-to-work statistics that will soon be available. Other aspects of this effort include improved geographic coding capability, improved simulation network development, and improved capability to use and relate street inventory, traffic, and safety data.

One of the major elements needed to provide improved input data is better information concerning intercity commodity and person movement data for all transportation modes. Our office has already established the national railway-bill statistics program, which provides data on the movements of goods by rail at the detailed commodity level. Similar programs are under way to provide data on the movement

of goods and people by air, motor, and water. These programs will require the cooperation and joint effort of many federal agencies, particularly the Census Bureau. It is important to note that these data will be of use to the states beyond the purposes of the Biennial Needs Study. These are data that are extremely difficult and expensive to collect at the state level. They should become valuable in the general data base of statewide planning.

The question of information system support to the states is more complex. After the 1972 returns are in, they will be carefully studied for indications of reporting problems and changes in the process that would be desirable. In addition, a committee composed of state representatives and our field staff will review the entire process and make recommendations for 1974. Also, any of the models or processing systems used at the federal level will be available to the states. We are very interested in receiving suggestions and recommendations on the kinds of systems support assistance most needed by the states. These might be in the form of special computer package systems, systems designs, or processing assistance.

An appropriate time schedule might be as follows: (a) draft manuals out to the states by spring of 1972; (b) final manuals out to the states by June 1972; and (c) final reports in from the states by June 1973.

The goal is to give the states and urban areas a year to complete the reporting process.

We are budgeting for a fund of \$5 million per year to support the states' needs study process. In addition, equal or greater funding would be made available as a separate fund to the cities participating. This is substantially more than was available for 1972. The proportioning formula will be the same as that used in computing allocations in 1972.

INFORMATION SYSTEMS RELATED TO HIGHWAY PLANNING

Roy T. Messer, Federal Highway Administration

A number of current information systems are characterized by their orientation to the business community. That they provide timely and valid information is very important to an enterprise where profits and losses may hinge on how soon or how well a decision is made. However, the concepts involved in the design of a system for a commercial enterprise are just as applicable in a public agency such as a highway department. In both types of organizations it is important for the managers to make decisions based on current information. Both kinds of organizations are committed to producing a product as efficiently and economically as possible. An information system can be a significant tool in accomplishing this.

Highway planners are especially concerned with having a tool for the efficient handling of information. Aside from accounting information, most of the information in a highway department that is used for more than one purpose is handled by the planning unit. This unit usually collects and processes a greater variety of data into usable information than any other unit.

Because of internal and external reporting needs every state highway department has had to build an information system. These systems work because reports are produced and questions are answered. The systems were man-based for many years; today, they are computer-based.

Perhaps the term information system should not be applied to these procedures, especially if we think of a system as being a set of related parts that interact to achieve some objective. A closer look at these procedures shows related parts and achievement of objectives; however, in a number of cases there is little or no interaction of the parts. My staff found this to be the case during a review of information and data-handling procedures in the planning divisions of the state highway department. It was normal for organizational units to be responsible for obtaining the data and information needed in particular planning activities that they were involved in. Theoretically, this means that coordination among the departmental units was necessary to acquire all data. Frequently, it was found, however, that the various units tended to act autonomously. Any coordination among the units usually was a result of the sequential nature of the work. It typically was the case that the different units had slightly different data names and slightly different ways of storing and using data. Because exchange of information and data among units was a manual process these differences became significant. Further, the units emphasize different aspects of the activities. Besides causing duplication, these things made it difficult to determine the status of a particular activity and the effect of any change in one activity on other activities. The duplication of effort was caused by the units' collecting and processing all the data they needed and relying very little on exchange of information.

We are certain that a similar review in other highway department functional areas would have similar results. We know the results are valid with respect to planning. It seems fair to say that until recently information processing has not been adequately systematized, and, in many cases, this is still true today. Even when the use of computers provided more sophisticated data-handling techniques, we seemingly were more concerned with processing data than with establishing methods to provide information.

Obviously, an information system in a planning division should do more than just reduce duplication. Such a system can be an important tool in developing the program of

improvements of every state highway department. During and after the development of a plan, various alternate plans and other modifications can be made. Also, an assessment of the impact of these changes on the total program can be made. An information system, which can take into account current and future availability of funds and manpower, distribution of projects within the state, and interrelationships of projects, will provide valuable information to the engineer and administrator.

The program is based on current and future highway needs, which are derived from projections of functional and structural obsolescence of highway segments. An information system can provide both kinds of information by tying together the data base resulting from routine planning survey operations and the specialized data base used in transportation planning models.

States are required to meet certain standards with respect to accident information, including maintenance of files about vehicles, vehicle operators, accidents, highway environment, and capability to analyze accidents in relation to the roadway environment. Although highway planning divisions are not solely responsible for this information, they have, for years, obtained and used these data for accident analysis, evaluation of need for improvements, and other internal reporting. An information system can be the means for providing this information to all interested parties without duplication of effort.

Many reports prepared by a planning unit are required periodically, but others are a result of special requests. Although it cannot be designed and built to answer all special requests, an information system can make preparation of the responses--to say nothing of the routine reports--much easier.

There are, of course, other benefits to be derived from an information system that need not be discussed here. The point is that different kinds of data and different information needs can be united through coordinated procedures; that is, they can become part of a system to provide information.

It is generally agreed that an information system must be tailored to a particular user. No one yet has successfully transplanted an information system, even when the organizations are similar. For this reason, it is necessary for a planning division to develop its own system according to its own needs.

The first, and probably most important, step in developing a planning information system is a clear and concise statement of the objectives of the system and a list of the steps to be taken to accomplish the objectives. Another necessary factor if the system is to be accepted and fully used after completion, is the involvement of all management levels in the development effort. It is equally important that other members of the organization be involved as well. Working-level personnel are most familiar with the data being collected and used, and it is from this group of employees that the most valuable information about data requirements will come.

One must recognize the ultimate use of the various data when designing the system, which should be information-oriented and not just data processing-oriented. Determination of data requirements is vital, but it is also very difficult. Because it is impossible to state accurately future data uses, there should be procedures to drop as well as add data at a later date.

Many of the users of the system will not have data processing or systems experience; therefore, complicated methods will discourage use of the system. One expert in the field has pointed out that an information system will tend not to be used whenever it is more painful and troublesome to have the information it produces than not to have it (1, p. 197).

The planning units of several highway departments are now developing systems similar to the one for which we have outlined concepts in a technical report (2). We call it a coordinated data system, but different names are used in different states. Several other states plan to start work soon on such a system, and a few states are currently working on department-wide information systems.

From this, we can see that there is increasing recognition of the value of information (as opposed to processed data) and the value of coordinated procedures for supplying information. This is only the beginning, however, because there are still many states that have not initiated strong efforts to build an information system. Even where such systems exist, there is still a need for improvement before we have systems

that tie all planning information together. Before we have such systems, there will probably have to be a general change in the attitude of our organizations about information. Management at all levels, because they are steeped in traditional ways of handling data and because they are ignorant of new equipment and processing techniques, often seem unable to envision new and better ways of displaying and using information. It would be a waste to develop an information system that processes information in the same way it has been done for the past 25 years. The potential uses of planning information systems are broad and numerous; we must learn to take advantage of them.

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PROGRAMS OF THE U.S. BUREAU OF THE CENSUS RELATED TO HIGHWAY PLANNING

Donald E. Church, Transportation Division, U. S. Bureau of the Census

This paper discusses the use of Census Bureau programs as input sources for socioeconomic data for automating highway planning. I am using the term automation in a broad sense that implies intensive use of computers and models for combining a wide spectrum of relevant facts or factors and distilling this mass of detail into a limited number of findings that can be used as part of the information base for making judgments and formulating policy.

Taken in this broad sense, almost all types of socioeconomic facts may be useful as input in some phase of an automation program. The most pervasive factor is population—its size, geographic distribution, and other characteristics as shown by the census of population and housing. The size, characteristics, and geographic location of economic activity also are influential. Sources of these inputs are the censuses of agriculture, manufactures, mineral industries, wholesale, retail, service industries, and construction. The census of transportation data provide a third dimension on interregional or interarea commodity and passenger flows as well as transportation.

Highway planning, by its very nature, must be dynamic and based on anticipated future situations. Benchmark data from the censuses, normally linked over time, are used widely in making projections for the future. Frequently, the projections are simple extensions of past trends; but, with the increased availability of computers and automated procedures, complex methods (including models) often are used that involve interrelationships among many basic factors. Among the census programs of value for quantifying basic relationships and factors for estimating probable trends are the well-known censuses and the current programs such as the annual survey of manufactures.

The Bureau has developed a substantial variety of computer software for its own use, some of which are applicable for automating highway planning. Among them are the "Admatch" package for assigning geographic codes to local records by matching addresses in a geographic base system. This is a method for automation of highly detailed geographic aspects within major urban areas.

The Admatch-Dime system may be characterized as "microgeographic" in contrast to the "macrogeographic" computer program, called PICADAD, which is used for automating all geographic aspects of the census of transportation. PICADAD is especially valuable for identifying origin-destination couplets in the nation as a whole, aggregating observations into selected origin-destination areas, and measuring straight-line distances between any given pair of areas that are not in the same city or locality.

Other Bureau publication programs of direct interest to automation, include the Statistical Abstract of the United States, which has been issued annually since 1878. The abstract is most commonly used as a handy source of data on a wide range of subjects. It contains an appendix entitled Guide to Sources of Statistics and source citations at the foot of roughly 1,300 tables and charts drawn from data issued by more than 200 federal, international, and private agencies. The source citation suggests the agency (or other source) that one may contact to obtain more details and further data.

A new source book is the Directory of Non-Federal Statistics for States and Local Areas, which was issued for the first time in March 1970. In addition, there are such general-purpose publications as the County and City Data Book, County Business Patterns, and Location of Manufacturing Plants.

Much of our work is related to information directly useful to the transportation field. The 1970 censuses of population and housing provide a wealth of detail on urban transportation problems. The census of population obtained the following information from a 15 percent sample of households: residence location, work location and transportation mode used to travel to work during previous week. This was supplemented by the census of housing, which obtained data on the number of automobiles owned or regularly used by members of the household.

The ability to couple the residential location with the work location provides a powerful tool for computing "travel desire lines" and a host of other urban highway planning applications. (This is the subject of the Highway Research Board Special Report 121.) The distribution of automobiles within urban areas provides a measure of the availability of private transport. The usefulness of both of these sets of data increase manifold when combined with other small-area statistics relating to land use patterns, and income levels.

The census of transportation is designed to obtain data to fill, or at least narrow, the serious gaps that exist in the transportation data field. So far, the program (divided into three surveys) has been concerned principally with intercity and interstate transportation and aimed specifically at three "blind spots": the nation's truck fleet, transportation of commodities from point of production to market or redistribution point, and passenger travel. Each of the surveys is based on samples rather than complete enumerations. The primary objective is to obtain national data, with as much state or other area detail as feasible.

The truck inventory and use survey provides estimates of the number of trucks and truck-miles classified by such characteristics as size, body type, occupational use, area of operation, and fleet size. With respect to geography, estimates are presented for each state and are divided into three ranges of operation—local, short range (beyond local but usually not more than a 200-mile radius), and long range (more than a 200-mile radius). The 1967 final report contains nearly 700 pages—mostly tables—designed to meet general public needs. Even that many tables did not exhaust the potentially useful data obtainable from the survey. Consequently, a public-use tape is available (at cost) for special analyses.

One geographic difference between the truck survey and the other parts of the transportation program is worth emphasizing at this point: The truck survey shows the vehicle population and characteristics in specified geographic areas (states, divisions, and regions), but it does not include origin-destination or flow data. On the other hand, the main thrust of the commodity and travel surveys is flow data, showing origin and destination areas insofar as feasible.

The commodity transportation survey provides data on the intercity shipment of commodities originated at manufacturing plants. Information includes means of transport, size of plant, size of shipment, and distance and other spatial relationships between point of production and destination. The 1967 survey was based on a probability sample of about 1.4 million shipping records, and the final report contained roughly 2,700 pages. As judged by the number of requests for additional details or different breakdowns, that voluminous report did not nearly exhaust the potential of the survey. Public-use tapes have been created that provide maximum detail without disclosing activities of individual establishments or companies.

The creation of public-use tapes as well as special-purpose tapes or special tabulations, especially in the commodity transportation and travel areas, leads to a problem we all share. One side of the problem is the fact that the demand for origin-destination detail is almost infinite. The other side of the problem is the equally realistic and stubborn fact that the supply of origin-destination and related detail is limited, in relation to the demand.

The main factors that limit data supply are the following:

1. Budget;
2. Response effort or reporting burden;
3. Avoidance of disclosure of individual, plant, or company activities; and
4. Ability of respondents to understand the questions asked and supply reliable answers.

Budgetary issues and the need for minimizing response burdens are so well known that we do not need to discuss them further at this time. Legal and other reasons for avoiding disclosure are also well known but worth some brief comments.

The need expressed for origin-destination data rarely is for "all-commodity" aggregates from point A to point B. Generally the need is for specific commodities between those two points and often for further breakdowns by size of shipment and means of transport. The main source of disclosure in this type of situation is the identification of a commodity at a specific origin because that information alone often discloses the producer. The most frequent solution is to combine commodities until a sufficient mixture of different shippers are involved to avoid disclosure or to cluster geographic points into broader areas, or to do both. Although this solution is less than ideal, it is often unavoidable even if the sample includes most (or all) of the plants in the area.

Another factor that limits data supply is the ability of respondents to interpret the questions asked and to supply reliable answers. This concept is so obvious that you may wonder why I mention it, but I assure you that it is an extremely serious limitation and often is not recognized by the survey statistician or data user. For example, several years ago in a travel survey, we asked people to answer questions regarding trips they had taken "since the beginning of last month"—a recall period of only about 6 weeks because the interviewing was done at about midmonth. The recall period was short, and we defined the term trip so clearly that there seemed to be no chance of confusion. The public cooperation was excellent, and the responses appeared to be good, complete, and reasonable. However, we later found that most people apparently did not know when "the first of last month" actually occurred. We discovered this by running two independent samples with partially overlapping time periods.

In a subsequent travel survey, we found that the clear definition of a trip—defined as being out of town overnight or going to a place 100 miles away—was logically precise and unambiguous but actually was not fully believable by respondents. For example, one person reported that he had not taken a trip during the last three reporting months. However, we subsequently interviewed him on a quality check and found that he had spent almost every weekend with his mother, who lived some 70 miles away. He said that he did not think we would consider those visits a trip, and he did not want to give us "bad" information. We found that the idea of merely being out of town overnight is not considered to be a trip in so many instances that we now define travel only in terms of a significant distance—100 miles away from home. Travel for distances nearer home must be measured in some other manner. Another example is the general absence of records that could be sampled to obtain data on such things as elapsed time in transit, transportation costs, and travel expenditures.

In brief, I have indicated two types of situations in which the necessary data cannot be obtained and published—one because of disclosure limitations, the other because reliable replies are not obtainable, because of either response errors or lack of records. In both instances, it may be feasible to construct estimates with acceptable accuracy (not necessarily close precision) by using data that can be collected and by applying factors to estimate data that cannot be collected or at least published. For example, a strong need has been expressed for origin-destination commodity flow data in terms of value of products. Bills of lading and most other shipping documents show weight but not value. The reporting burden on shippers, in my opinion, would be unreasonably high if they were asked to report the value of each shipment in a sample needed for measuring traffic flows. The most promising alternative is to obtain a set of factors, such as approximate value per pound, that can be applied to the tons of commodities shipped, provided the need by data users for value of shipment statistics is sufficiently great to offset the cost of obtaining and processing adequate factors.

A similar situation exists with respect to travel, in which there is a demonstrated need for travel expenditure data, especially with respect to increases or decreases in expenditures to be anticipated from future variations in the volume and characteristics of travel. The essential raw data are not a matter of record and, in my opinion, cannot be obtained in a mass survey with adequate precision. The most feasible alternative is the development of expenditure factors to be applied to data in the national travel survey, such as the number of trips by traveler income level and purpose of trip.

Some progress has been made in applying this type of solution, largely under the name of "model building" or "simulation" or "automation." This approach doubtless will continue to gain momentum, especially if survey statisticians and model builders cooperate more closely. The survey statistician should not only be the supplier of input data needed to obtain realistic answers but also the proposer of modifications to the models so that existing or obtainable data are more effectively used. Unfortunately, too many simulations are only exercises in logic and mathematical procedures, because they require inputs that cannot be measured in the real world. I also hasten to add that too many survey statisticians have not made a real effort to obtain the specific data needed for input to existing models. Progress in this type of solution necessarily will be slow, but it promises great dividends.

DEVELOPING A STATEWIDE HIGHWAY DATA BASE IN TEXAS

J. E. Wright, Texas Highway Department

Our first step in developing a statewide highway data base was to perform a systems analysis of current procedures. First we reviewed and analyzed all data sets maintained by the Planning Survey Division. We also reviewed and analyzed the existing reports and the format of all reports currently required. A report was then prepared of the methods of analysis and preparation of all reports and existing files maintained.

The selection of a data base was necessary before conversion was made from the existing tab shop operation to the proposed computer system. Before further movement was made, all possible alternatives that could apply to the various data sets were considered. Consideration was given to existing related data sets in other divisions and departments for maintenance of compatibility. Location reference systems that were considered included uniformly spaced mileposts, nonuniform mileposts, and coordinates. In the final selection, consideration had to be given to the existing controls used for current mileage and financial logs. After considering current requirements and existing data, format, and uses, we determined that a coordinated data system must include county, control and section within the county, and the beginning and ending mile point of each section as defined by its controlling break. These mile points are actual measurements to $\frac{1}{1,000}$ mile. Reference mileposts that closely reflect the actual mileage are located along the roadway for accident-location use. All files and data items were combined as far as possible to eliminate duplication and to group each class of data into a separate coordinated data set. Mile points were correlated between existing data records and straight-line diagrams. The actual locations of mileposts are also noted on the straight-line diagrams. All data were edited for accuracy and completeness as the new files were generated.

Maintenance of the systems had to be considered at the same time development was made. Data processing flow diagrams were prepared, file update programs were written, and the contents of all reports were reviewed to determine usefulness and completeness. After this was accomplished, the report programs were written.

It was necessary to plan the implementation and development of this system such that it would not interrupt the regular flow of the existing work program. Parallel operations were conducted during the period that the computer files were being developed; this continued until they proved to be reliable and could be fully substituted for the old methods. During this period, all files were correlated with the common reference base, that is, the county, control, section, and beginning and ending mile point.

To continue the preparation of existing reports and to furnish the required data, we developed eight coordinated data sets. All sets, of course, were developed using the common reference base. The following are currently maintained data files.

<u>File</u>	<u>Number of Records in File</u>	<u>Number of Data Items per Record</u>
State highway system, roadway characteristics (RI-2)	87,000	39
County road system, roadway characteristics (RI-6)	160,000	22
Bridge log	44,000	51 (currently)

<u>File</u>	<u>Number of Records in File</u>	<u>Number of Data Items per Record</u>
Accident data (annual)	350,000	70 (maximum)
Road life, cost data (RL-1)	161,000	50 (average)
Railroad crossing data	2,400	35
City street mileage summary	7,500	10
Traffic log	66,500	41

Any of these data may be combined by computer process to produce individual or combination reports with full correlation of the various data items.

The statewide data base and related files discussed thus far are currently maintained on tape and disk and are processed by batch methods. We are now entering phase two of the systems analysis to justify the need and extent of a terminal inquiry system. The need for existing data by other divisions and districts within the department and the addition of data to the existing files to make them more useful will be studied carefully. Close coordination will be maintained with all areas of the department to avoid any unnecessary duplication of data.

It is believed that a terminal inquiry system can be justified by the need for immediate access to current data. Also, specific information can be obtained without reference to voluminous printed output. This should result in more extensive use of available planning data.

Full consideration will be given to the selection of files: the level of detail maintained in each of these files, the method of file update such as direct data entry or batch processing, the direct-access storage space required, and the availability and type of terminals to be used for inquiry.

We now have the hardware and much of the software necessary to implement a statewide data base with direct-access capability to the most important files.

Our hardware availability consists of two IBM 370, Model 155 CPUs. Available soon will be the 3330 disk drives to replace the existing 2314 drives. We use the IBM OS operating system and AMIGOS file management software package. We now have the capability to design and implement an inquiry system for the coordinated statewide planning data files and are studying and planning this application.

PART VI
SUMMARY

WHERE DO WE GO FROM HERE WITH AUTOMATION SYSTEMS?

C. L. Miller, Massachusetts Institute of Technology

Our country is going through a rather profound and basic change that will directly and indirectly influence everything we do in the future of automation systems. We are undergoing a change in values and priorities. Quality is of greater importance now than quantity; more is not necessarily better. The broad social values, the quality of life, and the quality of the environment outweigh the more clearly defined economic values. The consequences of these changes and values are indeed profound, and we must take them fully into account.

It is not easy to adapt to these changes. We have all been conditioned by a heritage in which industrial and economic development was a near-sacred national goal. Progress was measured in economic terms and transportation development was the backbone of such progress. Indeed, in the past 50 years, the highway program has been in the forefront of the development of our country. The goal is now being changed somewhat, and the adjustments that we are faced with are painful, complex, and perplexing. Rather than fear them, however, I think we should take leadership in effecting them. We should be active students and active participants in these changes. These value shifts will not occur immediately, although some people are impatient and want to try to force that to happen. The changes will tend to be implemented during the 1970's and will tend to start to be reflected in the body politic as the full force of recent judicial and legislative decisions take effect. The "one man, one vote" decision and the decision to lower the voting age to 18 years are going to change the makeup of many legislative bodies. We should not fear this; we should anticipate it, take it into account, and not be surprised with some of the ramifications of it.

All of this may sound pretty far removed from "Automation Systems: Where Do We Go From Here?" I feel, however, that it is important that we understand the future environment within which we will work and that we have a proper perspective of those forces of change. Professionals in engineering and information systems tend to be somewhat preoccupied with serving top management. That concern for the chief administrator should be not just to meet his historical needs but to anticipate his future needs. Those of you responsible for highway automation systems should keep your top managers posted on such things, for example, as how many relocation family units must be provided in years ahead, what the rate of growth is of the noise level on certain urban expressways, and how many lawsuits are likely to result. Many types of information such as these are going to become more and more important in your work, and they are going to achieve the importance now given to financial status reports. That you should keep abreast of changes in computer technologies is obvious. Keeping abreast of social and value changes in this country, however, is much more difficult, but those changes may influence your future far more than technological changes.

I believe that we will agree that we have not quite finished the job in automation systems that we set out to achieve in the 1960's. We are continuing with that effort, and we must continue it. There is some danger in becoming absorbed fully in working on the problems as we defined them in the past and in trying to finish old jobs rather than in giving attention to new ones that are emerging as the missions of the organizations we work for constantly change. The considerable reorganization that will undoubtedly occur in the years ahead is going to be at the price of some confusion and uncertainty during the transitions.

Many organizational changes are made to integrate related functions and these offer a whole new source of opportunities for automation. Therefore, far from resisting those changes, people who are concerned with automation systems should be taking a certain degree of initiative and leadership in helping blueprint those kinds of organizational structures that are appropriate to our modern age. Bringing together various modes of transportation is simply a long overdue example of integrating related functions. Relating transportation in turn to regional and community development is also a logical move. In the process, data processing and automation can set the good example, for computers, procedures, and methodologies are neutral. They are equally adept in the planning, designing, managing, and operating of not only highways but also airports, public transit, urban renewal, utility resources development, and environmental monitoring control. In all of these areas, they can serve not only engineers but economists, sociologists, other kinds of professionals, and all kinds of managers.

Someone has to take the leadership in these moves to handle larger problems and newly defined arrangements. By default to a certain extent, this leadership is going to ex-aeronautics, ex-NASA people who are starting to occupy lots of top positions largely because they have self-confidence in being able to do most anything. I think that they can teach people in the highway field something about self-confidence. The people who have been working in the highway program for many years, in my opinion, have skills and experiences that are far more appropriate in solving social problems than those of probably any other professional segment. There has been a tendency, however, for highway engineers to maintain a narrow and often defensive view of themselves and to preserve the highway program at all cost. Such an attitude sharply limits the role that we could and should be filling as professionals in this country. We can indeed be proud of what we have accomplished in developing the highway system but there are now bigger and broader tasks that must be undertaken, and those of you associated with automation can assume a great deal of leadership.

With respect to highways, there is another factor that has come into reasonable focus and that is important in automation systems: We recognize that our main thrust in the past has been the building of highways. Most of our professional manpower effort has gone into creating highways: planning, design, and construction. Maintenance and operation have been secondary in levels of professional inputs. Clearly we are not going to stop building highways, but we are going to be much more concerned in the future with the efficient operation of the enormous investment we now have in highway facilities.

Automation of highway operations will be by far the big technical effort that many of you will be concerned with in the future. This constitutes a somewhat different kind of technical and computer problem than what we have dealt with before and is as much of a change in computer technology as going from the old tab operations to the stored program computer. I think that we can expect to see the forerunners of truly and highly automated highways before the end of the 1970's. The forecast is that they will probably be dual-mode facilities for small, publicly owned vehicles. One lesson that we should have learned from the past is that there is some danger that we are still making the basic mistake of trying to automate essentially manual procedures. What we automate and how we automate it are still subject to a lot of mistakes. I would like to use the analogy of automating garbage disposal. One form that such automation could take is to develop a mechanical man who would pick up the garbage can, empty it into the truck, and then bang it three times on the pavement. That would be automating the manual procedure. An alternative is to develop an electrically operated sink disposal, and to automate in that form takes somewhat of a redefinition of the problem, defined not as the emptying of garbage cans but as the disposal of garbage. The systems analyst or the automation expert must similarly seek new problem definitions and not merely automate what is currently being done. Indeed, if he did the latter, he would probably not come up with a better solution because automated garbage men are probably not cheaper than real garbage men. You probably could not improve on the manual method, and you would make an expensive, clumsy use of automation. The sink-disposal approach itself may not be cheaper, but it may be justified in larger nonquantifiable terms such as being convenient or eliminating health hazards.

There have been hundreds of examples of automating manual procedures, and they have been a source of great disappointment in many highway departments. We must redefine problems in larger terms; we must evaluate the value achieved in terms other than simply money saved. I caution you also about looking entirely to management, or the people currently handling the problem, for the answers for what they want and how they think it should be done. What would you expect the management of a garbage collection company to come up with as a statement of the problem in automating the garbage collection? It would be quite different from the analysis that would lead you to develop the innovative sink disposal. The garbage man himself would probably not be too helpful in giving you the information you need to automate his function. The systems innovator must be far enough away from the problem to see it perspectively, and he must use a great deal of imagination, skill, and judgment in coming up with new solutions. He must fully understand the intricate interrelations that exist everywhere. For example, in automating garbage disposal, he may create a new problem in terms of overloading the larger sewage distribution-collection-treatment system.

I would like to return to my basic theme and try to summarize as follows:

1. Take a much broader view than has been taken in the past of what automation systems are all about and do not limit your role in data processing;
2. Be bold and have self-confidence in being able as professionals to play a much larger and broader role, and do not think and act like technicians or you will be so treated;
3. Be prepared to go beyond the traditional domain of the state highway department in serving the public; and
4. Anticipate changes in the environment and the organizational structure within which you will work and be aware of changing values in missions as well as in changing technology.

For the past decade and a half, automation has been a newcomer and has had to sell itself. Much time and effort have gone into selling computers and automation and in getting new methods used and accepted. It has not been easy, and a certain psychic has developed that automation is peripheral to the organization and the servant of top management and others, that automation personnel are not generally understood, and that we have to talk to each other to be understood. I suggest that we have to break out of that psychic (even though, admittedly, a great deal of selling remains to be done) and stop acting like salesmen. Where we should and can go with automation systems now is to the center stage as a mature, essential, and central function without which the mission of any organization cannot be accomplished. Accordingly, there is a call for a change in our mental attitude from servants to leaders.

My answer to how you get the attention or support of top management of the future is to start filling such ranks yourselves. The chief executive of the future can and many should come from your own ranks. This is already starting to happen in some industries. It came as quite a surprise in the rather staid conservative Boston community that the new president of the State Street Bank is a computer man. Lawyers and financial men are the people who have traditionally been able to move up into top positions while engineers stayed down. This is due partially to the opportunity they have had to cut across divisional boundaries, to get to know and understand the whole organization, and to be close to its basic mission at the top. You have that very same characteristic now in the nature of your work, and you should take full advantage of it.

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