TRANSPORTATION RESEARCH RECORD 867

Transportation Programming Process

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1982

Transportation Research Record 867
Price $7.00
Edited for TRB by Brenda J. Vumbaco

modes
all

subject area
11 administration

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Transportation programming process.

(Transportation research record; 867)
Reports prepared for the 61st annual meeting of the Transportation Research Board.
Includes bibliographical references.
1. Transportation and state–United States–Congresses.
2. Transportation planning–United States–Congresses.
I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 867 [HE206.2] 380.5'068 82-24528
ISBN 0-309-03371-3 ISSN 0361-1981

Sponsorship of the Papers in This Transportation Research Record

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Kenneth W. Heathington, University of Tennessee, chairman

Management and Finance Section
Ira F. Doom, Huntsville Department of Transportation, chairman

Committee on Transportation Programming, Planning and Systems Evaluation
Henry L. Peyrebrune, New York State Department of Transportation, chairman
Dan C. Dees, Illinois Department of Transportation, co-chairman
Virginia J. Ainslie, James H. Banks, William G. Barker, Edward A. Beimborn, Melvyn Cheslow, James B. Chiles, Lewis P. Clopton, Donald O. Covault, Gary R. Erenrich, Joel Ettinger, William J. Fognini, Leonard Goldstein, Frederick Gottemoeller, Robert E. Heightchew, Jr., Clinton L. Heimbach, William S. Herald, W. M. Hilliard, Thomas F. Humphrey, James Dan Jones, Robert L. Knight, John T. Lancaster, Sr., Douglass B. Lee, Jr., Marvin L. Manheim, Richard D. Morgan, Monty C. Murphy, Charles William Ockert, Ian V. Oliver, Robert E. Paaswell, Robert L. Peskin, Marshall F. Reed, Jr., Philip D. Robers, L. W. Rulien, Tom K. Ryden, Charles C. Schimpeler, David F. Schulz, Kumares C. Sinha, Pearson H. Stewart, Darwin G. Stuart, Robert C. Stuart, Antti Talvitie, Theodore G. Weigle, Jr., James N. Wilson, Yacov Zahavi

Kenneth E. Cook, Transportation Research Board staff

The organizational units, officers, and members are as of December 31, 1981.

Contents

Authors of the Papers in This Record

Barbaresso, James C., Oakland County Road Commission, Birmingham, MI 48010
Bowser, Lee H., Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
Brand, Daniel, Charles River Associates, Inc., 200 Clarendon Street, Boston, MA 02116
Bryer, Thomas, Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
Haack, Harvey, Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
Kutz, Scott A., Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
Labadie, Michael J., Traffic-Safety Department, State of Michigan Board of County Road Commissioners, 2420 Pontiac Lake Road, Pontiac, MI 48054
Larson, Thomas D., Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
McManus, James F., California Department of Transportation, 1120 N Street, Sacramento, CA 95814
Muthusubramanyam, M., School of Engineering, University of Portland, 5000 North Willamette Blvd., Portland, OR 97203
Nelson, Charles A., Charles River Associates, Inc., 200 Clarendon Street, Boston, MA 02116
Poister, Theodore H., Institute of Public Administration, Pennsylvania State University, 211 Burrowes Bldg., University Park, PA 16802
Sinha, Kumares C., School of Engineering, Purdue University, W. Lafayette, IN 47907
Taylor, Roy, Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120
Zeiss, Warren W., Center for Program Development and Management, Pennsylvania Department of Transportation, Transportation and Safety Bldg., Harrisburg, PA 17120

Improved Highway Program Management Through Use of Integrated Information Systems

SCOTT A. KUTZ AND WARREN W. ZEISS

Managing the highway portion of a transportation program has become increasingly difficult for many state transportation organizations. In spite of this, however, the Pennsylvania Department of Transportation has succeeded in delivering improved service to the state's citizens. A key element employed by management in revitalizing Pennsylvania's highway program has been the development and integrated use of several information systems that are responsive to the extremely fast pace that characterizes highway program management. Five highway-related information systems are discussed. These systems are making contributions in the project selection and approval, preconstruction, and construction phases. They also provide data used in preparing the Department's cash flow estimate. Each system fulfills a primary management need, but all five have the capability of communicating with each other. In addition to the benefits of minimizing redundant data and improving data reliability, this integrated approach also facilitates the summarizing of data as they are moved from one system to another. This summarizing capability permits personnel throughout the Department to work with data at the level of detail required for their own tasks. While additional development work still remains, the results of employing an integrated systems approach are clear even at this point: The Department's management can make informed decisions on scheduling the efficient use of dwindling resources at a time when this sort of control is essential to providing a vastly improved transportation program.

Managing the highway portion of a transportation program has become increasingly difficult for many state transportation organizations. The Pennsylvania Department of Transportation (PennDOT) has seen its revenues and buying power severely cut by the combined effects of inflation and reduced fuel consumption. At the same time, however, it has committed itself to delivering improved service to the state's citizens. Under the direction of a new management team since 1979, the Department has aggressively implemented a fresh philosophy of operation that has succeeded in revitalizing Pennsylvania's highway program. Detailed information documenting these improvements has been published elsewhere (1,2).

One of the initiatives involved a fresh look at the manner in which the Department's computerized information systems should be developed and managed. While significant complement reductions were occurring throughout the organization, the requirement still existed to increase operational productivity. One of the keys to the Department's successes in the face of this challenge to "do more with less" has been the development of information systems that are responsive to the extremely fast pace that characterizes highway program management.

The integrated use of five of these information systems is discussed in this paper: the Project Management System (PMS), the Project Inventory (PI), the Consultant Agreement System (CAS), the Contract Management System (CMS), and the Structures Inventory Record System (SIRS). Each system fulfills a primary management need but, just as important, all five have, or will have, the capability of communicating with each other. In other words, a person using one system can retrieve data from another system by taking advantage of "linkages" designed into and between systems. This communications (interface) capability is the result of the fresh look that has been taken at the development of information systems in the Department; "stand-alone" systems that are unable to communicate with related systems are a thing of the past. At the time this paper was being prepared, all the information systems discussed here were at least in the final design phase. Some are already in production and others are in the implementation phase.

The integration of these systems has significantly improved the effectiveness of managing the highway program. In the planning stages, individual projects are selected and moved through the approval process more rapidly. Closer control and monitoring are now possible in the preconstruction activities leading up to the bid opening. Improvements in managing the construction phase are evident both to Department personnel and to contractors. Department personnel have the tools to develop, track, and administer each contract, and contractor invoices are being paid much more rapidly. The need to estimate cash requirements for various projects exists at all phases of the work, and these information systems provide data for the Department's cash flow estimates.

The paper will discuss the contributions that the five systems make to the project selection and approval, preconstruction, and construction phases. Their role in cash flow forecasting will also be discussed. Before getting into those specific areas, however, a discussion of the highway program management environment and a brief overview of the five systems will be presented.

HIGHWAY PROGRAM MANAGEMENT ENVIRONMENT

Pennsylvania's state-owned highway system includes 45 000 miles and 27 000 bridges. It is the fourth largest in the nation in total miles on a state system. Because the three larger states (Texas, Virginia, and North Carolina) do not have to contend with severe winters, Pennsylvania's highway system is among the most difficult to maintain.

For purposes of transportation, Pennsylvania is divided into 11 engineering districts. Their locations and a representation of the communications network used to provide district access to the centralized information management systems are shown in Figure 1.

A primary characteristic of highway program management is that it is anything but static. The level of available funding from federal, state, and local sources is often uncertain. Natural disasters require immediate redirection of resources. Legal definitions concerning the Department's ability or requirement to pay for certain types of projects from specific funding sources change periodically. Legal opinions concerning the types of projects that require legislative approval prior to starting work also can change. Each change of definition or opinion requires a revision of the overall highway program. Although these changes make it even more difficult to manage the program, the necessary adjustments must be made quickly to ensure that the state can secure the maximum return on the investment of its highway dollar.

The heart of the highway program management function is the Department's Program Management Committee (PMC). It is chaired by Transportation Secretary Thomas D. Larson and is composed of all the deputy secretaries and selected high-level managers. The PMC meets weekly and reviews each proposed project to be undertaken by the Depart-

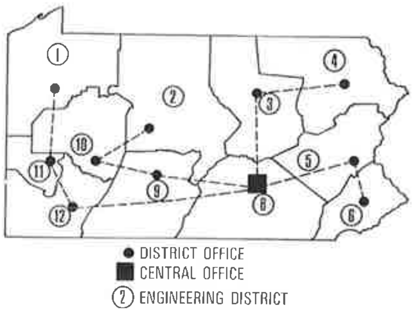


Figure 1. Location of state's 11 engineering districts and representative communications network related to information management systems.

ment. It makes the final decision concerning a project's approval or disapproval. (This process does not include the general maintenance program because this work is not controlled at the individual project level.) As a guideline, the PMC works with an extended 12-year program (legally mandated and based on operating cash resources), a 4-year program, and a 1-year program. Each program is coordinated with either actual or anticipated federal obligation authority, as well as state and local resource projections, to ensure that the Department's long- and short-range projects are planned and scheduled in accordance with available resources.

To support the PMC in its planning functions, a Center for Program Development and Management (CPDM) serves as the staff clearinghouse for all PMC actions and information requests. The CPDM is responsible to the Deputy Secretary for Planning and has three divisions: Project Assessment, Program Development, and Program Monitoring. It is charged with the responsibility for centrally managing the development of all Department highway-related programs except the general maintenance program. Technical staff assistance for some programs is provided to the CPDM by the Bureau of Highway Maintenance (betterment or restoration projects) and the Traffic Operations Division in the Bureau of Highway Services (safety projects). The Bureau of Highway Design also plays a key role in processing required documentation for federal aid projects and monitoring the projects to ensure that bids are received in accordance with published Department schedules.

Once a project is approved, responsibility for accomplishing the work rests with the Deputy Secretary for Highway Administration. Preconstruction activities are administered by the Bureau of Highway Design and the construction phase is administered by the Bureau of Contract Quality Control. The accumulation of expenditure data occurs in the departmental accounting system, which is the responsibility of the Comptroller. The projection of cash flow estimates is coordinated by the Fiscal Division in the Fiscal and Systems Management Center with raw input to the estimates supplied by many organizations throughout the Department. Achieving an optimal balance between the current federal aid funding levels, the state funds available or anticipated for matching the federal funds, the level of state funds to commit to non-federal aid work, and the ability of local governments to provide matching funds for federal-local projects is difficult at best. To make responsible decisions on future projects, the PMC must continually remain aware of the commitment represented by ongoing projects. It accomplishes this by enforcing strict cost control.

Engineering districts are required to justify any increase in estimated project costs that exceed the approved project costs by more than a specified tolerance. Then the PMC either approves the additional funds, requires a reduction in project scope to remain within available funding levels, authorizes a project substitution, or cancels the project.

Most of the activities just mentioned are supported either totally or in part by the integrated use of information systems. In general, this results in any given system providing service to a number of different central office bureaus and district office sections. These systems are designed and implemented by data-processing personnel in the Fiscal and Systems Management Center. The development process involves heavy participation from the managers and staff in the various user bureaus.

INFORMATION SYSTEMS OVERVIEW

This section will provide brief overviews of the five highway-related information systems and the Department accounting system addressed in this paper.

Project Management System

The PMS is used to monitor all programmed projects controlled by the PMC. It integrates project-related data from the engineering and planning communities with the accounting data from the financial community. Its data bases are centralized and updating is performed on-line by users located in both the central office and engineering district offices. As such, the PMS is essentially an "electronic filing cabinet" that contains the equivalent of an "electronic manila folder" for each project on the state's program. An extensive description of the system and its capabilities is provided elsewhere (3,4).

The on-line updating also permits the PMS to serve as a powerful communications tool because a change made from anywhere in the state is instantaneously available to all system users. An automatic message-sending capability is used to notify selected users of all changes to specified data fields. This helps eliminate problems that can develop if changes in a project's schedule or cost estimate occur without notification to concerned personnel.

The PMS also has an on-line inquiry capability. This permits managers to selectively interrogate their portions of the project data base without having to contend with large hard-copy listings.

The Department's objectives in developing the PMS are listed below:

1. Identify the PMC-controlled projects on the Department's program and monitor the status of their federal funding;
2. Track the physical and fiscal progress of each project by maintaining information concerning previous activity, current status, and future estimates;
3. Eliminate confusion that results from multiple lists of project-related information by maintaining common data bases for statewide use; and
4. Enable information requests to be met by inquiring into the data base(s) (maintained as part of daily operations) instead of short-fuse telephone inquiries to the engineering district offices.

Project Inventory

The PI, as the name implies, is the repository for data relating to all programmed highway projects. In this area, the PI contains data on all PMC-controlled projects that are planned for the future, currently active, or previously completed.

A portion of the projects in the PI constitutes the Department's 12-year program, a legally mandated listing of highway improvement projects to be undertaken in the next 12 years. The PI employs a centralized data base and updating is accomplished on-line by users located both in the central office and the engineering district offices. Access to the project data maintained by the PI is available to system users either on-line through cathode ray tube (CRT) terminals or through the use of standard report-generating packages.

The Department's objectives in developing the PI are listed below:

1. Establish a data base containing all viable proposed transportation improvement projects;
2. Maintain historical data on all completed projects;
3. Provide a mechanism for moving project data into the PMS as soon as the project is approved by the PMC;
4. Simplify the procedures used by the engineering district offices to submit candidate projects for inclusion on the Department's various programs; and
5. Provide the ability to produce reports quickly in response to the numerous inquiries received concerning past, present, and/or future projects.

Consultant Agreement System

The CAS is used to track the progress of the agreements executed between the Department and consulting engineering firms for the purpose of engineering design and activities associated with highway projects. Its data bases are centralized, and updating is performed on-line by users located in the central office. Inquiry capability also exists for users in the engineering district offices. Access to the consultant agreement data maintained by the CAS is available to system users either on-line through CRT terminals or through the use of standard report-generating packages.

The Department's objectives in developing the CAS are listed below:

1. Monitor the progress of all consultant agreements;
2. Identify agreements nearing expiration to ensure that they are closed in a timely manner;
3. Provide fiscal control on individual agreements by preventing expenditures that would exceed approved amounts;
4. Provide a communications tool that will permit instantaneous transmission of consultant agreement information; and
5. Enable information requests to be met by inquiring into the data bases with a standard report generation package

Contract Management System

The planned use of the CMS is to administer construction contracts. It provides a tool for performing all functions required from the development of the engineering district's initial design proposal and estimate through the generation of contractor payments and completion of the contract. Its data bases are centralized and updating is performed on-line by users located both in the central office and in the engineering district offices. The CMS provides capabilities in text processing as well as the basic capture, processing, and retrieval of contract information.

In the area of text processing, the CMS will assemble and print the bid proposal package and the subsequent construction contract from both standard and contract-specific text.

The data-processing capabilities of the CMS significantly reduce the processing time for actions associated with contract administration, e.g., contract estimate calculations, work schedule development, preparation of bid proposal and contract documents, bid evaluation and tabulation, processing work orders for schedule and/or cost adjustments, processing contractor payments, and monitoring claims. Inquiry capabilities into the contract data maintained by the CMS will be available either on-line through CRT terminals or through the use of standard report-generating packages.

The Department's objectives in developing the CMS are listed below:

1. Monitor the progress of all construction contracts;
2. Reduce the time necessary for the preparation of contract-related documents;
3. Forecast cash flow requirements for active construction contracts;
4. Speed up the evaluation and tabulation of bids;
5. Establish centralized data bases to provide a common data source for information relating to contracts, contractors, and standard contract items;
6. Speed up the approval of work (change) orders;
7. Expedite contractor payments;
8. Maintain a history of completed contracts; and
9. Provide enhanced reporting capabilities by using standard report-generating packages to summarize contract-related data.

Structures Inventory Record System

The SIRS is used to maintain detailed data on the inventory, inspection, repair, and condition of the bridges in Pennsylvania that have a length of 8 ft or longer. The system name includes "structures" to eliminate any confusion with the Federal Highway Administration (FHWA) definition of a bridge, which is a structure greater than or equal to 20 ft in length. The SIRS, therefore, contains data on more physical structures than are required to meet FHWA reporting requirements. Its data bases are centralized, and updating is performed on-line by users located both in the central office and in the engineering district offices. The data entered into the SIRS are obtained primarily through scheduled inspections performed on each structure. In addition to making these data available to department engineers, the system also writes specified information onto computer tapes that are then mailed to FHWA to satisfy established reporting requirements.

The Department's objectives in developing the SIRS are listed below:

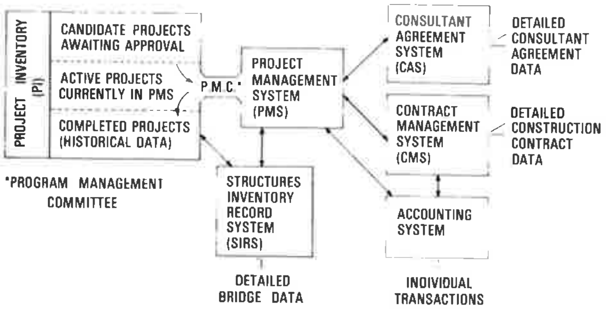
1. Monitor data on the inventory, inspection, repair, and condition of all bridges (structures) in the state greater than or equal to 8 ft in length,
2. Generate computer tape files of bridge data to meet FHWA reporting requirements, and
3. Provide a means of summarizing and reporting structures data through the use of standard report-generating packages.

Department Accounting System

The use of an accounting system is obvious. Perhaps the most notable property of the Department's accounting system as it relates to information management is the system's age. The accounting system was written approximately 15 years ago--the "dark ages" relative to contemporary data-processing techniques.

The accounting system tends to be a stand-alone system. It has only limited capabilities for com-

Figure 2. Integration of information systems.



*PROGRAM MANAGEMENT COMMITTEE

municating (via common data base keys) with other highway-related information systems. This fact has influenced the design of the systems described above because it was imperative to ensure that they stored the keys to the accounting data base. These keys are used typically to retrieve expenditure data against the various accounting charge numbers. Future plans call for increasing the communication capabilities of the accounting system.

INFORMATION SYSTEMS INTEGRATION

The integration of the five information systems and the accounting system is depicted in Figure 2. The arrows show the interface capabilities between the various systems. The interfacing capability is made available when the key field of one system is stored in another system. As shown in the upper center portion of Figure 2, the PMS bears the primary responsibility for accessing detailed data stored in the other highway-related systems.

To establish the proper context, it must be pointed out that the information systems being discussed are relatively new, at least in their present form. As mentioned earlier, all of the systems were at least in the final design phase as this paper was being prepared. The PMS and CAS are entirely new, while the others have had some form of a "previous version" that performed some similar functions. The systems integration efforts are concerned only with the newly implemented versions.

The PMS was the first of these systems to be developed. The other systems have been designed for their own specific purposes but all have included the appropriate interfacing capabilities. Not surprisingly, there is a need to gain some experience with any given two systems before the interface between them works smoothly. At times, redundant or inconsistent data are located and must be reconciled. Standardizing coding conventions between two groups of users who have historically worked separately is also an important requirement. The Department is actively pursuing efforts to identify and eliminate these sources of inconsistency. This results in improved data quality and increased confidence from the user community.

The Department has realized (or can realize) a number of benefits from using these systems as an integrated package instead of treating each as a stand-alone system. The need to maintain redundant data is minimized. Individual data items are stored in one of the systems but can be accessed from any other system through the linkages shown in Figure 2. A direct benefit from minimizing redundancy is that retrieved data are guaranteed to be consistent and the most current available simply because they are only being stored in one place and accessed from any number of systems. Previously, each system would have stored its own "version" of a data item so that it was difficult to decide which one was more current.

For an alternative look at the information systems, Figure 3 depicts the organization levels served. The "length" of any of the bars within one of the three levels is intended to provide a qualitative indication of the "usefulness" of the system in providing on-line information at that level. For example, the accounting system provides only transactional data used by the technical staff. CMS will accept transactional input data and also be capable of providing data summarized to a point that would be of use to middle management. The PMS and PI can accept transactional data but, compared with the other systems, are more heavily employed in providing data to middle and top management. The small penetration of the bars into the top-management level demonstrates that the Department still does not have a truly effective system for providing strategic information. This is discussed further in the section on future plans.

Figure 3 shows that many levels in the Department are served. The integration permits the users to access data at a level of detail representative of their own needs. The technical staff, accustomed to working at a transactional level with the data in their area of expertise, enter and retrieve data in this detailed format. In contrast, management personnel need to have the data condensed into meaningful summaries in order to properly discharge their duties; the higher the level of management, the broader the summary. Although the "raw" data are transactional in nature, the systems integration permits these detailed data to be extracted from the system in which they were originally input, summarized by the PMS, and presented in a format suitable for management decisions. As mentioned above, more enhancement is needed in the preparation of summaries for top-level management.

The following sections discuss the use of systems integration in three major project phases: project selection and approval, preconstruction, and construction. The contribution made by the CMS and PMS to the Department's cash flow forecasts is also discussed.

Project Selection and Approval Phase

The project selection and approval process primarily involves the PI and the PMS. The SIRS may also be used to obtain current data related to candidate bridge projects. An overview of the project selection and approval process is shown in Figure 4. District offices submit projects for consideration by the PMC by entering the project into the PI. Lists of candidate projects are generated from the PI and analyzed by the CPDM staff and other concerned bureaus. The resulting recommendations are presented to the PMC. Once approved by PMC, a project's data are automatically copied from the PI into the PMS. The project will remain in PMS as long as it is active. Once completed, the project's data are moved from PMS back into PI where they remain as a historical record.

This process applies to all highway projects except those used to accomplish general maintenance. General maintenance activities are not directly controlled by the PMC and, therefore, are not included in the PI or the PMS. In contrast, the other systems shown in Figure 2 have a more general scope. Any consultant agreement will be in the CAS, any construction contract will be in the CMS, and the accounting system will record all expenditures, regardless of project type. The systems integration enables the PMC to "screen out" data on projects it

Figure 3. Organization levels served on-line by information systems.

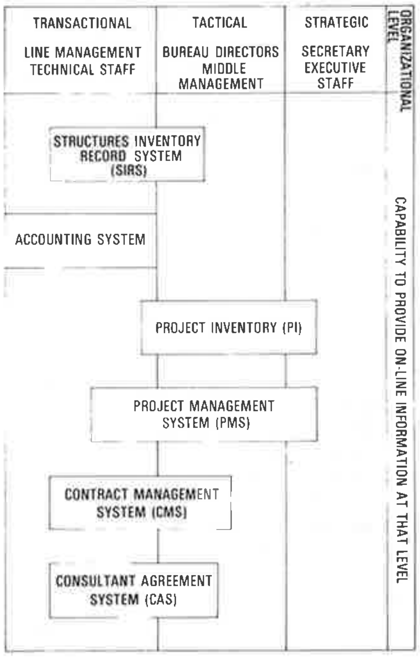
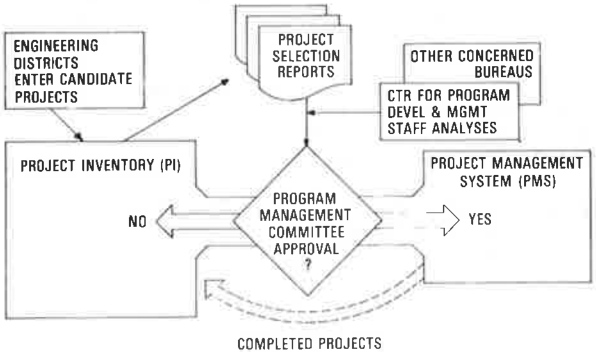


Figure 4. Overview of project selection and approval process.



does not individually control. By the same token, the Bureau of Highway Design and the Bureau of Contract Quality Control are able to maintain needed data on all consultant agreements and all construction contracts, respectively. In other words, the systems integration permits various organizations to function "separately" while using the same physical data bases.

Preconstruction Phase

Management during the preconstruction phase involves primarily the PMS, the CAS, and the CMS. The SIRS may also be accessed if detailed data are needed on a specific bridge.

The district offices record the progress of a project through its preconstruction phases by entering the achievement dates for specified milestones into the PMS. Some of the actual achievement dates are entered by central office users for activities controlled in the central office. The Bureau of Highway Design uses the CAS to maintain more detailed data (administrative data, invoices, and supplements) on individual consultant agreements.

The CMS will be used to capture data generated in the design phase that will be of use in preparing and administering an upcoming construction contract. The CMS enables the district to prepare its initial design estimate for a project and, at a later time, an FHWA-required breakdown of the project by classification of work items. Should any of this detailed data in either the CAS or CMS be needed for higher-level managers, they can be accessed by using the linkages stored in the PMS, as shown in Figure 2. The link between the accounting system and the PMS enables the PMS to report actual expenditures for preconstruction activities.

The end of the preconstruction phase is marked by the opening of bids for a construction contract. The PMS is used to generate the letting schedule, i.e., the list of projects for which bids will be received. The schedule is prepared every three months for the next six-month period. For each project, it lists the description, location, letting month, and the cost range. Only projects that conform to uniform selection criteria are placed on the published letting schedule. The schedule is used for control within the Department and is also distributed to the contracting industry to provide advance information on the projects coming up for bid. Once received, the evaluation and tabulation of the bids are accomplished by the CMS.

Construction Phase

Management during the construction phase involves primarily the PMS and the CMS. If required, the SIRS is also available to provide detailed data on bridges.

District office personnel enter a few major milestone dates for the construction phase into the PMS. The most detailed data for construction contracts will be maintained in the CMS (contract documents, administrative data, work schedule, invoices, and work orders). Should any of this detailed data be needed for higher-level managers, they can be accessed by using the linkage stored in PMS, as shown in Figure 2.

The CMS processes the contractor invoices and prepares the necessary accounting system transactions to generate the payments. The resulting expenditures are picked up by the PMS through its interface with the accounting system. This enables the PMS to report actual expenditures for the construction phase. The approach used in forecasting the cash requirements for these contractor payments is discussed in the next section.

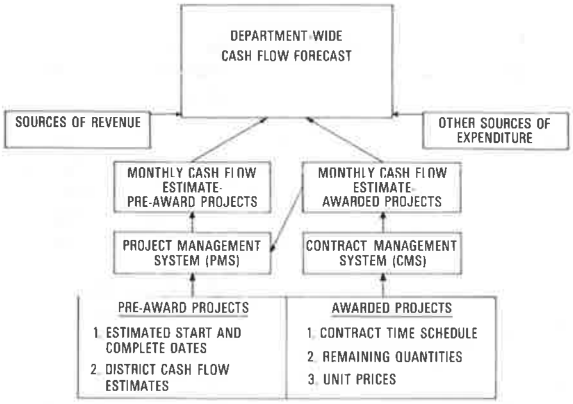
Cash Flow Forecasting

In the face of decreasing revenues and increasing costs, it is absolutely essential that the Department continually assess its cash position both now and in the future. The Department is making significant progress in refining its ability to forecast the amounts associated with its multiple sources of expenditure and revenue. A general overview of the cash forecasting process is shown in Figure 5. The top of this extremely simplified sketch shows that the PMS and the CMS contribute data to the "estimated expenditure" portion of the estimate. The approach to preparing the estimated contractor payments divides the projects into two major categories: pre-award versus awarded projects.

The cash flow forecasts for projects that have not yet been awarded are prepared from estimates entered into the PMS by engineering district users. The techniques for calculating these estimates are described elsewhere (5).

The cash flow forecasts for projects that have

Figure 5. General overview of cash forecasting process.



already been awarded will be calculated by the CMS from the information contained in the construction contract. The CMS combines the contract time schedule with the remaining quantities for the various line items and their corresponding unit prices to convert these data into a schedule of monthly cash needs for the next 24 months for each contract. These data are also made available to the PMS.

FUTURE PLANS

As mentioned above, the Department is engaged in a continuing effort to improve the interfaces between the highway-related information systems so that redundant data can be minimized and sources of inconsistencies removed. Other improvements are also planned. The Department has retained a consulting firm to assist in the development of a Fiscal Management Information Systems Plan. The recommendations of this plan will help fill the "void" in the upper portion of Figure 3 that depicts a shortage of suitable information systems for top management.

Another area in the early stages of development involves systems that maintain data on the entire continuum of the highway network. These inventory systems are much more difficult to develop than the project-specific systems discussed in this paper. No individual interfaces have yet been planned between the inventory-type systems and the project-type systems, but it seems reasonable to expect that as-built project data would be used to update the highway inventory systems.

CONCLUSIONS

PennDOT has made significant improvements in recent years in the development and use of its information systems. Substantial benefits have resulted from integrating the highway-related management systems.

Personnel at all levels in the Department have found that the integrated systems approach enables them to work with data at the level of detail required for their own tasks. However, data summarized to a more detailed or less detailed level can be made available to them if required.

The Department has continued to increase its operational productivity and the information systems are reducing the time required to accomplish many of the tasks associated with planning, designing, and administering construction on highway projects. They also provide a means for estimating cash flow requirements for construction contracts.

Managing the highway program is not going to get any easier so it is imperative that the Department continue to make progress in the area of integrating its highway-related information systems. The support provided by responsive systems will permit managers to make informed decisions on scheduling the efficient use of dwindling resources. This is an extremely important aspect of the Department's commitment to provide a vastly improved state transportation program.

REFERENCES

1. J.I. Scheiner. More for Transportation Dollars Through Productivity Improvement. AASHTO Quarterly, American Association of State Highway and Transportation Officials, Washington, DC, July 1981.
2. L.H. Bowser, H. Haack, and T.D. Larson. Program Development and Management--Pennsylvania's Integrated, Organizational Approach. Pennsylvania Department of Transportation, Harrisburg, July 1981.
3. S.A. Kutz. Programmed Project Management in Pennsylvania--Statewide Data Access. TRB, Transportation Research Record 826, 1981.
4. S.A. Kutz and J.I. Scheiner. Computer Management of Transportation. Rural and Urban Roads, Scranton Gillette Communications, Inc., Des Plaines, IL, March 1981.
5. S.A. Kutz. Rationale for PMS Cash Flow Estimates. Pennsylvania Department of Transportation, Harrisburg, Feb. 1981.

Development of Priority Program for Roadside Hazard Abatement

MICHAEL J. LABADIE AND JAMES C. BARBARESSO

A computerized roadside hazard inventory was developed for the major county roadways in Oakland County, Michigan. The study included the development of a priority program used to rank roadside hazards for removal or protection. This program included various safety factors that have an impact on the relative hazardousness of roadside obstacles and other features that obstruct the "clear recovery area" along a roadway. A weighting scheme was used to aggregate the safety factors. The procedure is designed to be applicable to all highway operating agencies, especially those with access to a computer. The entire data file has been computerized in such a way as to be capable of aggregating and summarizing information concerning various roadside hazards. The data system can be updated as necessary, thus it is kept current at all times. The system can be used to rank roadside hazards according to their relative priority factors. It can

also be merged with fixed-object accident data and roadway geometric data currently on file to augment the system's analysis capabilities. Finally, multidisciplinary teams can review each of the highest-priority hazards and/or locations and can determine possible countermeasures.

Knowledge of the location and relative hazardousness of roadside hazards is essential if engineers are to effectively improve the safety of the roadway and its environment. Efforts to remove or protect roadside hazards generally result from public complaint, construction projects and/or traffic accidents and not a planned, ongoing program. This approach often results in sporadic work efforts and ignores many severe hazards. Substantial litigation expenses and settlements are often incurred by operating highway agencies because a planned correction program for roadside hazard abatement generally does not exist.

If roadside hazard data are continuously collected and maintained, engineers will be able to prepare realistic short- and long-range improvement plans, develop optimal correction programs, and maintain a safer roadway environment for the motoring public--traditional efforts to address the problems of roadside obstacles that have not been allowed. They require significant time and labor and may not produce the most cost-effective results because a priority program is not used.

The approach outlined in this report deviates from the traditional method of roadside hazard abatement. A computerized inventory file of roadside hazards was compiled from an existing set of photologs, and each hazard was ranked according to the potential hazardousness it presents. Non-accident indicators were used to develop the priority scheme. The use of non-accident indicators supplants the reactionary nature of past approaches, wherein a hazard is removed or protected after an accident has occurred, with a priority scheme based on the relative probabilities of collisions occurring with obstacles.

Although non-accident indicators are used to rank roadside obstacles according to their potential hazardousness, the approach presented in this report allows the integration of computerized accident data and roadway geometric data with the computerized inventory file of roadside hazards. This capability provides for more complete analysis of roadside hazards.

This paper describes the priority scheme used in the development of a roadside hazard abatement project in Michigan. First, the study site and characteristics are outlined. Next, the ranking scheme is explained, followed by a discussion of the data-collection process. Finally, the use of this scheme and its implications for project management are explained.

STUDY AREA

The study area for this project was Oakland County, Michigan, which is part of the tri-county Detroit Metropolitan Area. The roadways included 1206 km (750 miles) of paved county roads and 482 km (300 miles) of unpaved county roads under the jurisdiction of the Oakland County Road Commission (OCRC). The program did not include subdivision streets. All inventoried roadways were classified as county primary or county local.

PRIORITY SCHEME

Previous research efforts regarding roadside hazards indicate a need for a program of this type (1). Attempts have been made to define the potential hazardousness of roadside hazards and to rank these hazards according to some priority scheme, but these previous efforts did not use many variables that influence the potential hazardousness of roadside hazards (2-5).

In this study, the criteria used to determine the relative hazardousness of roadside hazards included the following:

1. Whether or not the roadway is curbed,
2. The presence of horizontal curves (inside or outside),
3. The presence of vertical curves (+ or - grade),
4. The rigidity of the object [see Table 1 (4)],
5. Average daily traffic,
6. Speed limit,
7. Distance from pavement edge, and
8. Roadway type (county primary, local, etc.).

Each of these criteria was assigned an appropriate evaluative rating of hazardousness ranging from 0 to 5 points (Table 2).

The overall priority factor, which was defined as a function of these criteria, included the following weighting scheme: curbing = 2; curve section (outside) = 5; curve section (inside) = 3; grade section (+) = 3; grade section (-) = 4; rigidity = 5; average daily traffic = 3; speed limit = 3; distance from pavement = 5; and roadway type = 2. The priority factor (PF) was then defined as a function of the hazardousness ratings and the corresponding weighting factors; i.e.,

$$PF = \sum_{i=1}^{n} H_i V_i \quad (1)$$

or

$$PF = H_1 V_1 + H_2 V_2 + H_3 + H_4 V_4 + H_5 V_5 + H_6 V_6 + H_7 V_7 + H_8 V_8 \quad (2)$$

where

V_1 = curb rating,
V_2 = curve rating,
V_3 = grade rating,
V_4 = rigidity rating,
V_5 = average daily traffic rating,
V_6 = speed limit rating,
V_7 = distance from pavement edge rating,
V_8 = roadway type rating, and
$H_1 \ldots\ldots H_8$ = corresponding weights (as described earlier).

The higher the value of the priority factor for a hazard, the greater is its relative hazardousness. Thus, those hazards with a high PF should be protected or removed first in order to reduce the hazard exposure to the motoring public and, ideally, the liability exposure of the agency with roadway jurisdiction.

DATA COLLECTION

The data base for this project was compiled through the use of existing photologs of OCRC roads. The individual frames of the photologs were reviewed by using a photoviewer with a special grid overlay that provided the reviewer with lateral distance measurement capabilities. The relevant data were coded onto a form specifically prepared for this purpose (Figure 1). The coded data were then typed into a computer terminal by using an interactive program that prompts the analyst to input the appropriate data. The following data were extracted from the photologs: street name, hazard type, district number, street type, direction of travel, side of street, curbed or uncurbed, distance from curb, and

Table 1. Severity factors for fixed objects of varying rigidity.

Fixed Object	Factor	Fixed Object	Factor
Utility poles (wood)	4	Hydrant	3
Supports-rigid (steel)	4	Signposts	1
Supports-breakaway	1	Trees (diameter in in)	
Guardrail	3	Greater than 13	5
Bridge abutment/wall face	3	11-12	4
		8-10	3
Bridge abutment and pier end	5	5-7	2
		2-4	1
Bridge rail faces	1	Rocks and boulders (diameter in ft)	
GM barrier	1		
Bridge rail end	5	Greater than 3	5
Fill slopes		2-3	4
2:1	5	1-2	2
3:1	4	Less than 1	1
4:1	3	Steel beams, concrete posts, etc.	3
5:1	2		
6:1	1	Wood posts (in)	
Cut slopes		8 x 8	2
0.5:1-1:1	5	6 x 6	2
1.5:1	4	4 x 4	1
2:1	3	Guy wire	3
3:1	2	Wood posts	
4:1 or flatter	1	6 x 8-in guardrail	2
		7-in round marker post	2

date of filming. Information related to road grade, object rigidity, traffic volume, and speed limit was obtained from other sources and merged with these data.

SYSTEM CAPABILITIES

On completion of the data-collection activities, computer software was developed to provide various safety analysis capabilities. In general, the software provided four functions: dump, search, update, and statistical analyses. Each of these functions is described below.

Dump

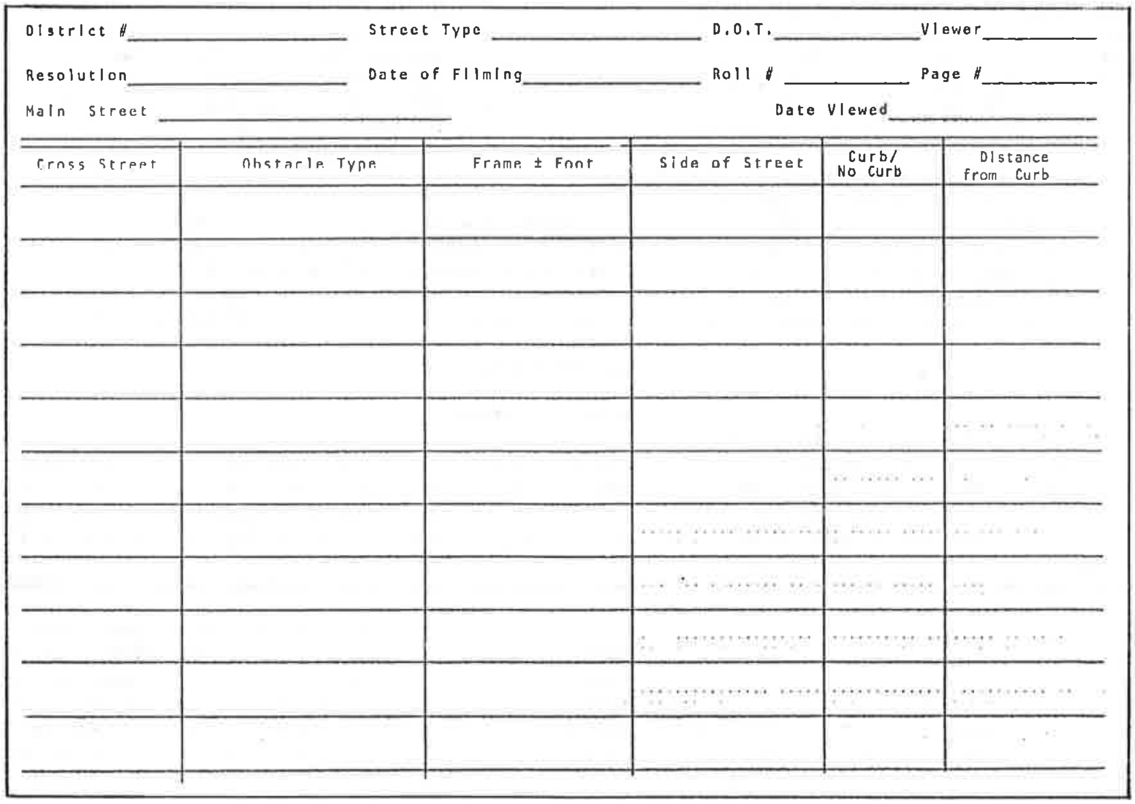
The dump function produces a printout of the complete roadside hazard inventory file (Figure 2). The output includes all of the variables necessary to determine the PF for each roadside hazard. Approximately 110 000 roadside hazards are cataloged alphabetically by road name. Each record (i.e., roadside hazard) is assigned a line number and a "milepoint" for easy reference.

Table 2. Hazardousness ratings.

Criteria	0	1	2	3	4	5
Curbed or uncurbed		Curbed	Uncurbed			
Curve section (°)	Straight	1-5	6-10	11-15	16-20	21+
Grade section (%)	Flat	1-3	4-6	7-9	10-12	13+
Rigidity		-[a]				
Average daily traffic		1000 or less	1001-8000	8001-15 000	15 001-20 000	20 000 or greater
Speed limit (mph)		25	30-35	40-45	50	55
Distance from pavement edge (ft)	Greater than 30	30-21	20-11	6-10	3-5	2 or less
Roadway type		Subdivision	Collector subdivision		Local	Primary

[a] See Table 1.

Figure 1. Data coding form.



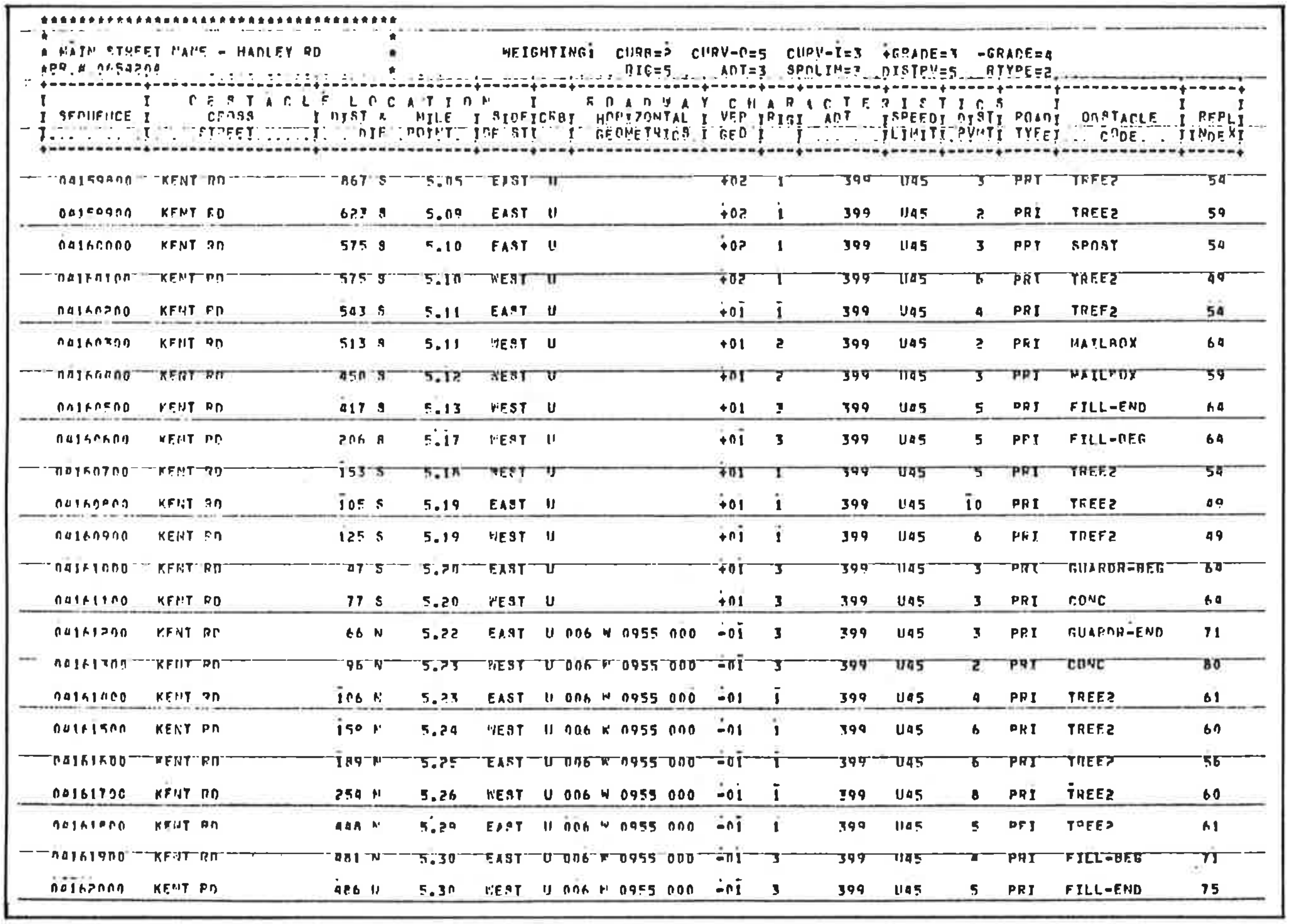
District #________ Street Type ________ D.O.T.________ Viewer________

Resolution________ Date of Filming________ Roll # ________ Page #________

Main Street ________ Date Viewed________

Cross Street	Obstacle Type	Frame ± Foot	Side of Street	Curb/ No Curb	Distance from Curb

Figure 2. Inventory sample printout.



```
****************************************
*                                      *
* MAIN STREET NAME - HADLEY RD         *         WEIGHTING: CURB=2  CURV-O=5  CURV-I=3  +GRADE=3  -GRADE=4
*RD.# 0654204                          *                     DIG=5   ADT=3  SPDLIM=3  DISTRV=5   RTYPE=2
+----------+--------------------------+-------------------+-----+---+---------+-----+-----+-----+--------------+-----+
I          I   O B S T A C L E   L O C A T I O N       I     R O A D W A Y   C H A R A C T E R I S T I C S     I              I     I
I SEQUENCE I     CROSS          I DIST &   MILE   I SIDEICRSI  HORIZONTAL  I VER IRIGI  ADT   ISPEEDI DISTI ROADI  OBSTACLE    I REPLI
I          I     STREET         I  DIR    POINT   IOF STI   I  GEOMETRICS  I GED I   I         ILIMITI RVMTI TYPEI    CODE      IINDEXI
+----------+--------------------------+-------------------+-----+---+---------+-----+-----+-----+--------------+-----+

  04159800   KENT RD                  867 S    5.05    EAST   U                    +02   1     399   U45     3   PRI   TREE2          54
  04159900   KENT RD                  623 S    5.09    EAST   U                    +02   1     399   U45     2   PRI   TREE2          59
  04160000   KENT RD                  575 S    5.10    EAST   U                    +02   1     399   U45     3   PRI   SPOST          54
  04160100   KENT RD                  575 S    5.10    WEST   U                    +02   1     399   U45     6   PRI   TREE2          49
  04160200   KENT RD                  543 S    5.11    EAST   U                    +01   1     399   U45     4   PRI   TREE2          54
  04160300   KENT RD                  513 S    5.11    WEST   U                    +01   2     399   U45     2   PRI   MAILBOX        64
  04160400   KENT RD                  450 S    5.12    WEST   U                    +01   2     399   U45     3   PRI   MAILBOX        59
  04160500   KENT RD                  417 S    5.13    WEST   U                    +01   3     399   U45     5   PRI   FILL-END       64
  04160600   KENT RD                  206 S    5.17    WEST   U                    +01   3     399   U45     5   PRI   FILL-BEG       64
  04160700   KENT RD                  153 S    5.18    WEST   U                    +01   1     399   U45     5   PRI   TREE2          54
  04160800   KENT RD                  105 S    5.19    EAST   U                    +01   1     399   U45    10   PRI   TREE2          49
  04160900   KENT RD                  125 S    5.19    WEST   U                    +01   1     399   U45     6   PRI   TREE2          49
  04161000   KENT RD                   47 S    5.20    EAST   U                    +01   3     399   U45     3   PRI   GUARDR-BEG     64
  04161100   KENT RD                   77 S    5.20    WEST   U                    +01   3     399   U45     3   PRI   CONC           64
  04161200   KENT RD                   66 N    5.22    EAST   U 006 W 0955 000     -01   3     399   U45     3   PRI   GUARDR-END     71
  04161300   KENT RD                   96 N    5.23    WEST   U 006 W 0955 000     -01   3     399   U45     2   PRI   CONC           80
  04161400   KENT RD                  106 N    5.23    EAST   U 006 W 0955 000     -01   1     399   U45     4   PRI   TREE2          61
  04161500   KENT RD                  159 N    5.24    WEST   U 006 W 0955 000     -01   1     399   U45     6   PRI   TREE2          60
  04161600   KENT RD                  189 N    5.25    EAST   U 006 W 0955 000     -01   1     399   U45     6   PRI   TREE2          56
  04161700   KENT RD                  254 N    5.26    WEST   U 006 W 0955 000     -01   1     399   U45     8   PRI   TREE2          60
  04161800   KENT RD                  448 N    5.29    EAST   U 006 W 0955 000     -01   1     399   U45     5   PRI   TREE2          61
  04161900   KENT RD                  481 N    5.30    EAST   U 006 W 0955 000     -01   3     399   U45     4   PRI   FILL-BEG       71
  04162000   KENT RD                  486 N    5.30    WEST   U 006 W 0955 000     -01   3     399   U45     5   PRI   FILL-END       75
```

Search

The search function produces a printout of data records conforming to specific parameters supplied by the system user. Any variable or combination of variables in the data file can be specified for a search. For example, if a user wishes to search the file for all records containing trees with diameters greater than 1 ft on horizontal curves of greater than 6 degrees, a printout containing all such records will be produced.

Update

An important aspect of this information system is that the data can be updated. As changes or improvements are made (e.g., a hazard is removed, protected, etc.), the inventory data can be altered or deleted, or a new record can be inserted. Historical records are also maintained so that changes can be monitored over time and to ensure that the data are correct. The update process involves completing a form (Figure 3) and inputting the new data to the files.

Statistical Analyses

In order to perform analyses that aid the OCRC in developing a roadside hazard abatement program, the inventory data can be manipulated and merged with other data files. The Statistical Package for the Social Sciences (SPSS) (6,7) is used to perform these analyses. The SPSS package provides various capabilities for the analysis of the inventory data. Individual data records can be analyzed or aggregate statistics can be generated. Capabilities range from frequency distributions and cross tabulations to multivariate regression analysis.

SYSTEM USE IN PROJECT MANAGEMENT

The dump, search, and update functions of this information system provide OCRC staff with up-to-date information necessary to the decisionmaking process. However, the statistical analysis capabilities of the system provide management tools that enable the development of a systematic program of roadside hazard abatement.

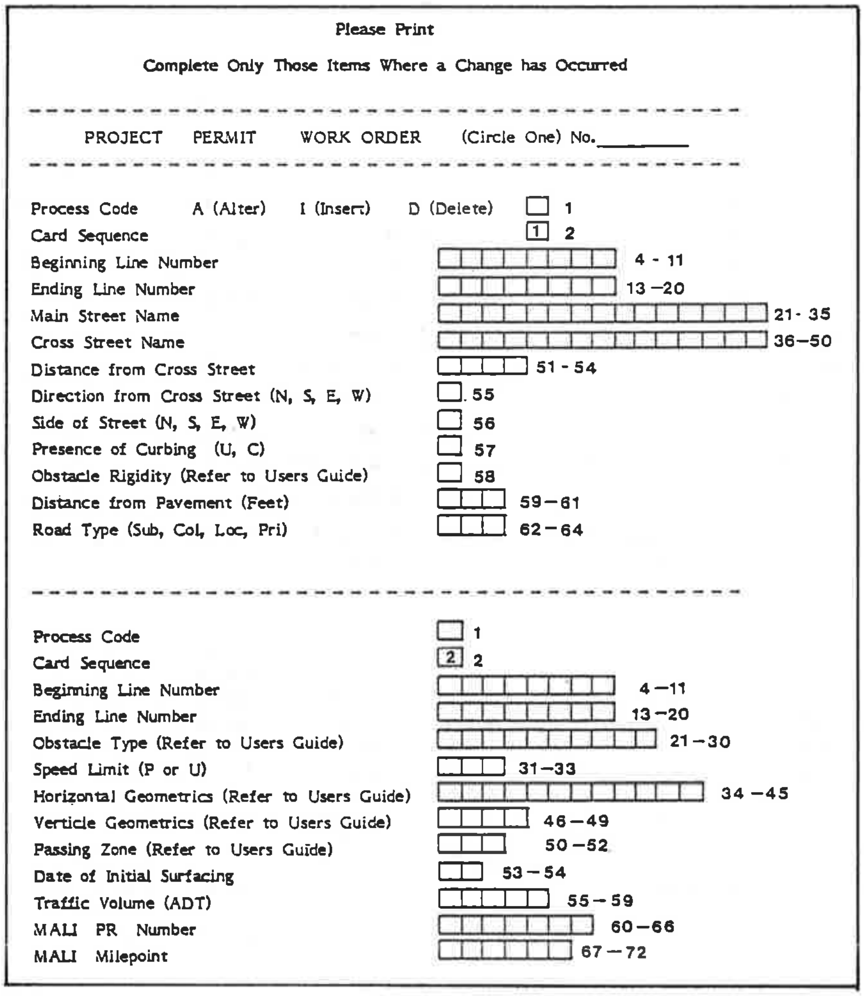
The statistical analysis capabilities allow the user to rank all roadside hazards by priority factor. In this manner, those roadside hazards that present the greatest potential for accident occurrences are treated with priority.

Decisions regarding the types of treatment (e.g., removal, relocation, protection, etc.) that are chosen for roadside hazard abatement can also be facilitated with this system. By altering one or more of the variables influencing the priority factor for a particular roadside hazard, various alternative treatments can be simulated and new priority factors will be calculated. The most effective treatment alternative is the one resulting in the lowest priority factor. Treatment costs can then be applied to determine the relative cost effectivensss of the alternatives. In this manner, the analyst can make decisions such as whether a guardrail should be installed on a particular fill slope or whether the slope should be leveled.

It is also possible to determine critical levels for each of the variables through the application of SPSS. These critical levels can then help in establishing policies for such activities as tree planting and landscaping, utility pole placement and installation, or guardrail maintenance and installation.

An additional feature of this inventory is that it can be merged with an existing accident data file and a newly completed roadway geometrics file, augmenting the analysis capabilities of the system. All roadside hazards are assigned to a particular roadway with a unique primary road number. The accident and roadway geometric files are also organized according to these primary road numbers, thus giving the files a common denominator. Individual roadside hazards, roadway features, and traffic accidents are assigned to specific milepoints for common reference within each primary road subfile. Therefore, the analyst is capable of reviewing all accident data and roadway geometric data for a location with a roadside hazard. Or, the analyst

Figure 3. Roadside obstacle update form.



Please Print

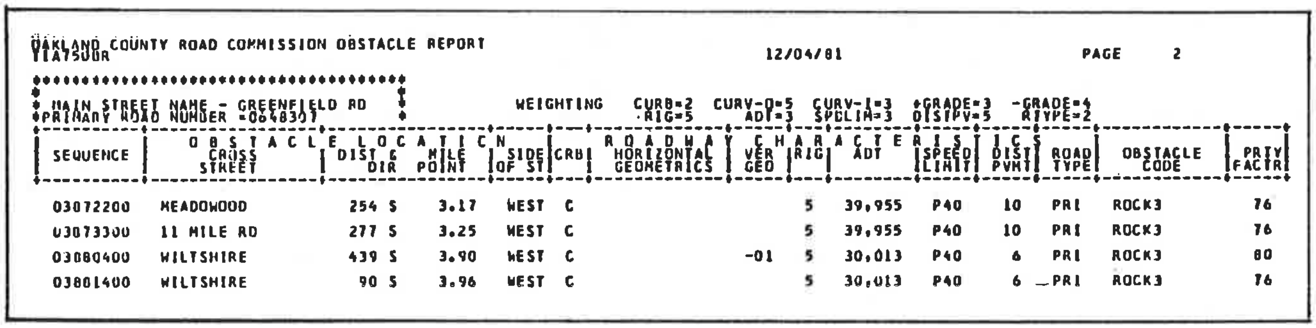
Complete Only Those Items Where a Change has Occurred

PROJECT PERMIT WORK ORDER (Circle One) No.________

Process Code A (Alter) I (Insert) D (Delete) ☐ 1
Card Sequence [1] 2
Beginning Line Number ☐☐☐☐☐☐☐☐ 4 - 11
Ending Line Number ☐☐☐☐☐☐☐☐ 13 –20
Main Street Name ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ 21 - 35
Cross Street Name ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ 36–50
Distance from Cross Street ☐☐☐☐ 51 - 54
Direction from Cross Street (N, S, E, W) ☐ 55
Side of Street (N, S, E, W) ☐ 56
Presence of Curbing (U, C) ☐ 57
Obstacle Rigidity (Refer to Users Guide) ☐ 58
Distance from Pavement (Feet) ☐☐☐ 59–61
Road Type (Sub, Col, Loc, Pri) ☐☐☐ 62–64

Process Code ☐ 1
Card Sequence [2] 2
Beginning Line Number ☐☐☐☐☐☐☐☐ 4–11
Ending Line Number ☐☐☐☐☐☐☐☐ 13–20
Obstacle Type (Refer to Users Guide) ☐☐☐☐☐☐☐☐☐☐ 21–30
Speed Limit (P or U) ☐☐☐ 31–33
Horizontal Geometrics (Refer to Users Guide) ☐☐☐☐☐☐☐☐☐☐☐☐ 34 –45
Verticle Geometrics (Refer to Users Guide) ☐☐☐☐ 46–49
Passing Zone (Refer to Users Guide) ☐☐☐ 50 –52
Date of Initial Surfacing ☐☐ 53 – 54
Traffic Volume (ADT) ☐☐☐☐☐ 55 – 59
MALI PR Number ☐☐☐☐☐☐☐ 60–66
MALI Milepoint ☐☐☐☐☐☐ 67 – 72

Figure 4. Rocks in right-of-way.



```
OAKLAND COUNTY ROAD COMMISSION OBSTACLE REPORT
TIA750UR                                                     12/04/81                       PAGE     2

**************************************
*                                    *
* MAIN STREET NAME - GREENFIELD RD   *          WEIGHTING   CURB=2  CURV-0=5  CURV-I=3  +GRADE=3  -GRADE=4
*PRIMARY ROAD NUMBER =0648301        *                       RIG=5     ADT=3  SPDLIM=3  DISTPV=5   RTYPE=2
+-----------+-------------------------+---------+------+---+----------+-----+---+--------+-----+-----+-----+-----------+-----+
|           |    O B S T A C L E   L O C A T I O N      |   |    R O A D W A Y    C H A R A C T E R I S T I C S    |           |     |
| SEQUENCE  |      CROSS       | DIST &  MILE  | SIDE |CRB| HORIZONTAL | VER |RIG|  ADT   |SPEED| DIST| ROAD|  OBSTACLE | PRTY|
|           |      STREET      |   DIR  POINT  |OF ST |   | GEOMETRICS | GEO |   |        |LIMIT| PVMT| TYPE|    CODE   |FACTR|
+-----------+-------------------------+---------+------+---+----------+-----+---+--------+-----+-----+-----+-----------+-----+

  03072200   MEADOWOOD          254 S    3.17   WEST  C                      5  39,955    P40    10   PRI   ROCK3         76
  03073300   11 MILE RD         277 S    3.25   WEST  C                      5  39,955    P40    10   PRI   ROCK3         76
  03080400   WILTSHIRE          439 S    3.90   WEST  C                -01   5  30,013    P40     6   PRI   ROCK3         80
  03801400   WILTSHIRE           90 S    3.96   WEST  C                      5  30,013    P40     6  _PRI   ROCK3         76
```

can review the roadway geometrics and the roadside hazards associated with specific fixed-object accidents. In combination, these files provide a comprehensive roadway information system for the OCRC.

ILLUSTRATIONS OF SYSTEM USAGE

Rocks in Right-of-Way

In the past, the OCRC has assigned a full-time staff person to inspect all county roadways for potentially hazardous conditions. One activity performed by this inspector was to report potentially hazardous obstacles within the road right-of-way. It was often the case that residents would place large rocks and other objects near the roadway in an attempt to keep vehicles from encroaching on their lawns and property. Many of these objects were placed where occurrences of off-road accidents were common. The safety implications of placing objects in such vulnerable locations are obvious.

In order to reduce labor costs and institute a systematic procedure for the correction of roadside hazards voluntarily placed within the right-of-way, a search program was run to identify such locations. The following command was issued to the computer:

```
TIA750BR0001SEARCH
TIA750BR0002OBSTACLE TYPE EQ ROCK3
TIA750BR0003DIST FRM RDWY LSS 010
TIA750BR0004VOLUME GTR 8000
TIA750BR0005FINISHED
```

This command printed data records (Figure 4) for all rocks, 3 or more ft in diameter, less than 10 ft from the pavement edge, and on roadways with greater than 8000 average daily traffic. Following identification of these hazards, investigation efforts were planned. Subsequent to investigation, letters requesting removal of the rocks are sent to the property owners.

Guardrail Maintenance Program

The OCRC maintains more than 2500 miles of county roadways. It, therefore, needs a systematic procedure for inspecting and maintaining guardrail on these county roadways.

A procedure of this type requires that the condition of all guardrail on the OCRC system be known. Furthermore, all of the guardrail locations must meet the current design standards. Finally, the effectiveness of the guardrail must be assumed to be reduced if it has been involved in a collision. Therefore, it is necessary to find guardrail locations where a fixed-object accident has occurred.

The data files (i.e., roadside hazard and accident data) must be merged to compile the necessary information. The following SPSS commands can be issued:

```
SELECT IF [(OBS34 EQ 0102 OR OBS34 EQ 0103) AND ACC10
   EQ 06]
REPORT FORMAT  = LIST, MARGINS (1,100)/
       STRING  = MSTN (OBSN01 OBSN02 OBSN03 OBSN04)
                 CRSTN (OBSN05 OBSN06 OBSN07 OBSN08)/
       VARS    = OBS05 'DISTANCE' 'FROM' 'IN FEET'
                 (12)
                 OBS06 'DIRECTION' 'FROM' 'INTERSEC-
                 TION' (12)
                 CRSTN 'CROSS STREET NAME'
                 OBS29 'PRIORITY' 'FACTOR'
       CHEAD   = 'DAMAGED GUARDRAIL'/
       BREAK   = MSTN 'MAIN STREET NAME' (LABEL)/
       SUMMARY = VALIDN MAX (OBS29)
```

This run will produce a listing of all guardrail locations where a fixed-object accident has occurred. For each case, the main street name, the guardrail location, and priority factor associated with the guardrail will be printed.

Once these locations are determined, repair crews can be assigned to repair the damaged guardrail. The schedule of repairs can be determined by the priority factor associated with each case. Those guardrail locations with the highest priority factors should be given priority for repair.

Other Uses

In addition to the two uses explained previously, OCRC is using the roadside hazard information system for other activities. The system provides the basis for an organized tree removal program. The search-and-sort capabilities of the system facilitate such programs. Another typical use of this system is a bridge railing maintenance and upgrading program. When merged with the accident and roadway information files, the system is useful in the development of safety improvement plans for various types of projects. With greater usage of the system, other applications, which will enhance the safety of OCRC roadways, will certainly be divulged.

CONCLUSION

The procedures described in this report provide an alternative to the current methods of roadside hazard abatement. With its computer application, this system provides the basis for many planning and operational activities with a low expenditure of man-hours.

The priority scheme for quantifying the relative hazardousness of roadside hazards allows the OCRC to systematically review those roadside hazards that present the greatest risk to the traveling public and the agency. The simplicity of this scheme permits its application to any highway agency or system, and its flexibility allows other agencies to adapt it to fit their own needs and priorities.

The information system is capable of providing current data regarding roadside hazards and can be merged with accident and roadway geometric data files to augment its data base. The search and statistical functions available with this system provide the OCRC with analysis capabilities that help in developing cost-effective safety treatments for various safety deficiencies. The result is a systematic program for enhancing the safety of OCRC roadways.

REFERENCES

1. J.L. Foley. Highway Safety and Roadside Hazards. Transportation Engineering Journal of ASCE, Vol. 106, No. TE6, Nov. 1980.
2. J.C. Glennon. Roadside Safety Improvement Programs on Freeways. NCHRP, Rept. 148, 1974.
3. D.E. Cleveland and R. Kitamura. Macroscopic Modeling of Two-Lane Rural Roadside Accidents. Presented at 57th Annual Meeting, TRB, Jan. 1978.
4. M. Horodniceanu and E.J. Cantilli. Transportation System Safety. Lexington Books, Lexington, MA, 1979.
5. R.A. Cunard and others. Computerized Inventory and Priority Analysis for Roadside Obstacles. Presented at 57th Annual Meeting, TRB, Jan. 1978.
6. N.H. Nie and others. SPSS. 2nd ed. McGraw-Hill, New York, 1975.
7. C.H. Hull and N.H. Nie. SPSS Update. McGraw-Hill, New York, 1979.

Optimization Approach in Highway System Analysis and Programming

M. MUTHUSUBRAMANYAM AND KUMARES C. SINHA

Inflationary pressures, stabilizing user tax revenues, energy constraints, rapid rise in highway improvement cost, and an aging system have necessitated the shifting of emphasis to highway system preservation and improvement. The highway system has to serve several objectives, and the problem is one of using limited resources optimally. A computer package that combines simulation and goal programming techniques has been developed to find the implications of policy changes and alternative macroeconomic futures to highway system improvement and performance. The package is applicable to a system of highways in one state or a group of states. A brief account of the model formulation and the application of the model in understanding the effect of varying levels of funding on highway improvement strategy is presented. The Indiana highway system is used as a case study.

The U.S. highway transportation system is in a state of transition. Rising costs of materials and labor combined with inflation, stabilizing tax revenues, energy constraints, environmental concerns, and changes in the national automotive policy decisions have made it imperative that available financial resources be spent judiciously on the maintenance and preservation of existing systems rather than on the addition of new facilities. An analytical tool to aid decisionmakers in the allocation of financial resources for highway maintenance and preservation is urgently needed.

The tool needs to be capable of addressing multiobjective optimization and also needs to be helpful in analyzing highway system performance as affected by future macroeconomic climate and policy changes. Such a tool, which uses goal programming techniques in combination with simulation has been developed at Purdue University. This model was applied to the highway system of Indiana (1,2) and also to the highway system within Region 5 of the Federal Highway Administration (3). A brief account of the model and of its applications to the State of Indiana is presented in this paper.

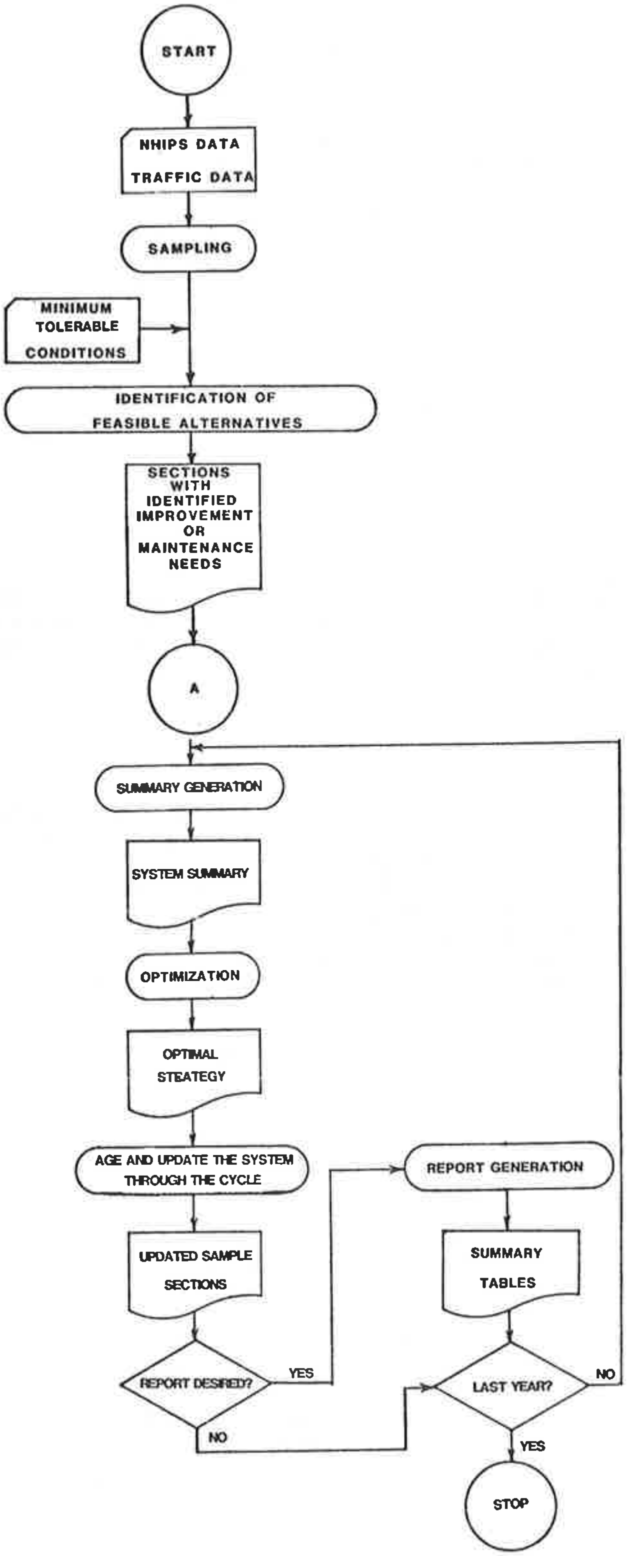
An overview of the study methodology is shown in Figure 1. The highway system is represented by sample sections together with attribute ratings simulated from summary data. The system summary developed by the National Highway Inventory and Performance Summary (NHIPS) in 1976 is used (4). Feasible activities are identified by applying minimum tolerable conditions to highway sample sections. An optimal strategy in terms of miles of each class of highway to be brought under routine maintenance or one of the six periodic improvement activities within given funding constraints is determined. The sections receiving improvement or routine maintenance are updated with respect to the corresponding attribute ratings, and all the sections are "aged." A new summary is generated, and the process repeated for the next cycle. The analysis can be done for a predetermined number of years by dividing the analysis period into cycles of suitable years.

The formulation of the optimization problem is presented in the next section, followed by a discussion of the results.

MODEL FORMULATION

The goal of highway system improvement is to satisfy the objectives of providing the users with a rideable surface, ensuring efficient and safe travel

Figure 1. Overview of the study methodology.



besides conserving energy and minimizing adverse impacts on the environment. With limited resources, it is impossible to attain all the objectives. A technique that is well-suited for this type of problem is goal programming (5,6). The optimization problem for a six-state region with six highway classes, four system objectives, and eight highway activities is presented below.

Optimization Model

1. System objectives are expressed as constraints:

$$\sum_{s=1}^{6} \sum_{i=1}^{8} p_{ki}X_{ihs} + d^{-}_{kh} - d^{+}_{kh} = T_{kh} \qquad \begin{matrix} k = 1, \ldots 4 \\ h = 1, \ldots 6 \end{matrix} \qquad (1)$$

2. Funding--the total federal share on eligible activities--should not exceed the regional allocation of federal grants:

$$\sum_{i=1}^{8} f_i \sum_{s=1}^{6} \sum_{h=1}^{6} C_{ih} X_{ihs} \leqslant B_F \qquad (2)$$

The total amount spent by each state including the respective share to match the federal grant cannot exceed available state funds:

$$\sum_{i=1}^{8} (1 - f_i) \sum_{h=1}^{6} C_{ih} X_{ihs} \leqslant B_s \qquad s = 1, \ldots 6 \qquad (3)$$

3. Feasibility constraints--the mileage under each activity in each class of each state--cannot exceed the identified needs for that activity:

$$X_{ihs} \leqslant a_{ihs} \ell_{hs} \qquad \begin{matrix} h = 1, \ldots 6 \\ i = 1, \ldots 4, 6, 7 \\ s = 1, \ldots 6 \end{matrix} \qquad (4)$$

Since resurfacing is considered to be an activity undertaken with federal grant (activity 5) or without it (activity 8):

$$X_{5hs} + X_{8hs} \leqslant a_{5hs} \ell_{hs} \qquad \begin{matrix} h = 1, \ldots 6 \\ s = 1, \ldots 6 \end{matrix} \qquad (5)$$

4. In consideration of equity constraints, it is desirable to meet at least a minimum of the identified need for various activities. Thus,

$$X_{ihs} \geqslant b_{ihs} a_{ihs} \ell_{hs} \qquad \begin{matrix} i = 1, \ldots 4, 6, 7 \\ h = 1, \ldots 6 \\ s = 1, \ldots 6 \end{matrix} \qquad (6)$$

$$X_{5hs} + X_{8hs} \geqslant b_{5hs} a_{5hs} \ell_{hs} \qquad \begin{matrix} s = 1, \ldots 6 \\ h = 1, \ldots 6 \end{matrix} \qquad (7)$$

5. The objective function is to minimize a weighted sum of the underachievements. Thus,

$$\text{Min } Z = \sum_{k=1}^{4} \sum_{h=1}^{6} w_{kh} d^{-}_{kh} \qquad \begin{matrix} h = 1, \ldots 6 \\ k = 1, \ldots 4 \end{matrix} \qquad (8)$$

Notation

h = 1, ... 6 highway classes;
i = 1, ... 8 activities;
k = 1, ... 4 objectives;
s = 1, ... 6 states;
a_{ihs} = fraction of class h in state s that needs activity i;
b_{ihs} = minimum need in activity i for class h in state s, expressed as a fraction of identified need;
B_F = budget provision from federal funds for one year for the whole region;
B_s = budget provision from state s for one year;
C_{ih} = unit cost of implementing activity i for class h (this could vary among states; in this analysis, however, national averages are used for want of more refined data);
d^{-}_{kh} = underachievement in objective k for class h;
d^{+}_{kh} = overachievement in objective k for class h;
f_i = fraction of cost of activity i that is federal matching grant;
ℓ_{hs} = length (miles) of class h in state s;
p_{ki} = activity-performance impact coefficients, impact on objective k due to activity i;
T_{kh} = standard (target) aimed at for objective k in class h;
w_{kh} = penalty for underachievement in objective k for class h; and
X_{ihs} = miles of class h in state s to receive activity i (the decision variable).

Applications of Model

The impact of different funding and maintenance policy options under alternative futures is an important issue to highway authorities who would be interested to know the performance of highway systems in terms of physical improvements as well as improvements in various system objectives. The specific issues of interest considered are briefly noted here.

FUNDING LEVELS AND POLICIES

Funding levels and policies were examined by considering the following questions:

1. How do different funding levels from various sources affect system performance?
2. As funding gets reduced, which highway classes are affected most? What is the extent of the impact of reduced funding?
3. If more funds were to become available, where should they be spent?
4. If a policy of allocating funds by category were changed and a state highway agency were given full freedom to use total funds on all highway activities (non-categorical funding option), what will the implications be?

The funding levels could be analyzed by generating anticipated revenues using a revenue forecasting model or by first determining total needs and then studying the effect of using varying percentages of this need.

RELATIVE IMPORTANCE OF SYSTEM OBJECTIVES

This model provides for input from policymakers in the form of priority weights for system objectives. The weights used were along the lines of those adopted in a similar study (7). If the policymakers want to see the implications of giving much higher priority for one objective (e.g., safety), the weights can be suitably altered and the model applied. In this study, an option of equal weights was considered. By comparing the results of this option with those obtained by using differential weights, it is possible to understand the trade-off in terms of highway classes and activities implied in a particular priority weight option.

RELAXED STANDARDS AND DEFERRED MAINTENANCE

Two of the strategies suggested to stretch highway money are (a) relaxing the standards and (b) deferring maintenance. The question of deferred maintenance is built into this package by using optimization. In other techniques of fund allocation, any strategy of deferred maintenance will have to be explicitly stated and the impacts predicted and compared with other options. In optimization, however, when the solution indicates only a fraction of the need in an activity-class combination to be met, the remaining fraction of that need is automatically deferred; thus, the model picks out what is to be deferred (by selecting what is best done now) besides giving the results in terms of achievement of system objectives, allocation funds, and system performance.

The question of relaxed standards can be one of lowering minimum tolerable conditions (thereby reducing the estimated need in one or more activities), or one of reducing the design standards (thus reducing cost rather than activities), or both. The impact of reducing minimum tolerable conditions that warrant various maintenance activities can be studied by feeding appropriate information at the time of identifying feasible alternative activities. The option to reduce design standards, though advocated in certain quarters, is likely to replace the whole system with a substandard one in the future. Hence, only the former option is considered here. The option of reduced standards can, however, be analyzed by modifying unit cost information to reflect the reduced design standard. The activity-performance impact coefficients will also have to be suitably modified (p_{ki} in Equation 1).

Alternative Futures

The current situation and trends in national economic aspects are different from those that existed for a long period of time until recently, and they are changing at an unpredictable pace. The most important questions are those related to the increasing price of gasoline and the fast decline in the purchasing power of the highway dollar. These important questions with respect to the future are analyzed by hypothesizing various scenarios and applying them in the model.

Retail Price of Gasoline

In this research, the projections published by the Southeastern Wisconsin Regional Planning Commission (8) were used. Four scenarios of future price of crude oil were considered. Based on these projections and assuming no real price change in gasoline taxes, refining, or transportation, four sets of figures for the price of gasoline in the year 2000 in constant (1979) dollars are derived. In the analysis reported here, the two extreme projections were chosen for consideration. These were combined with two taxation policies to derive two sets of future retail prices of gasoline.

Tax Policies

The incidence of gasoline tax changes the retail price of gasoline, and thus affects future vehicle travel and revenue from the gasoline tax. The consequent impact on highway revenue can be predicted by using a revenue-generation submodel and can be given as exogenous data in this package.

It is necessary to have vehicle travel projection as an integral part of the package because deterioration of highway conditions is a function of vehicular travel. The model developed in Mannering (9) is incorporated in the present package. The application of the methodology requires forecasts of the retail price of gasoline in constant dollars.

The current taxation practice and the anticipated revision in Indiana were considered. For regional application the package is designed to accept different tax rates in each state by inputting different gasoline prices into the module for projecting vehicle miles of travel.

In Indiana, the gasoline tax was $0.08/gal until 1979. The policy (as of this writing) is to charge an ad valorem tax of $0.08/$1.00 of the net price (exclusive of state and federal taxes) of gasoline, subject to a maximum of $0.12/$1.00, $0.14/$1.00, and $0.16/$1.00 in 1980, 1981, and beyond 1981, respectively.

An expected tax policy is stated in Indiana House Bill No. 1378 (March 1981). This implies a floor of $0.10/$1.00 on the first $1.00 of gasoline price, plus 8 percent of the price exceeding $1.00, subject to a ceiling of $0.16/gal.

Each of these two taxation policies could be combined with each of the two wholesale price forecasts mentioned earlier to get four gasoline price scenarios. However, two extreme scenarios--one obtained by combining the low gasoline price scenario with present taxation policy and another by combining the high gasoline price with proposed taxation policy--were considered in this analysis.

Commercial Vehicle Miles of Travel

The methodology adopted to forecast future commercial travel is described in Mannering (9) and Muthusubramanyam (3). Two extreme growth scenarios were chosen as explained in Muthusubramanyam (3). Each of these scenarios (or any other commercial traffic growth scenario) could be combined with each of the two gasoline price scenarios. In the analysis presented here, however, only two combinations were considered: The low gasoline price-taxation scenario was combined with the high commercial growth scenario, and the high gasoline price-taxation scenario was combined with the low commercial travel growth scenario.

Revenue Versus Cost

In recent years the cost of highway improvement and maintenance has been increasing at a rate faster than that of revenue. To be able to predict system performance in the future under such circumstances, we need to forecast revenue as well as the unit cost of each highway activity for each year in the future. This will involve enormous data files besides the additional tasks of forecasting these figures.

The critical question is one of differential growth of revenue and cost and not so much of the precise figures. Hence, a simplified methodology was adopted in this study by using a multiplicative factor to scale down the revenue at the year preceding the analysis to any future year, thus reflecting the real (reduced) revenue in relation to cost--without having to give revised revenue and cost figures.

Two revenue-versus-cost scenarios were analyzed. One scenario was to assume that revenue will keep pace with cost, while another scenario assumed that the recent trend will continue.

Combining each of these revenue-cost scenarios with each of the two macroeconomic scenarios described above, four scenarios can be developed. However, only three scenarios need to be analyzed in order to study the impact on highway system performance under different travel growth (as the revenue-to-cost relationship remains constant) and under changing conditions of the revenue-to-cost relationship (with travel growth scenarios unchanged).

In order to understand the impact of the macro-

Figure 2. Percentage of needs met in each highway class at various funding levels.

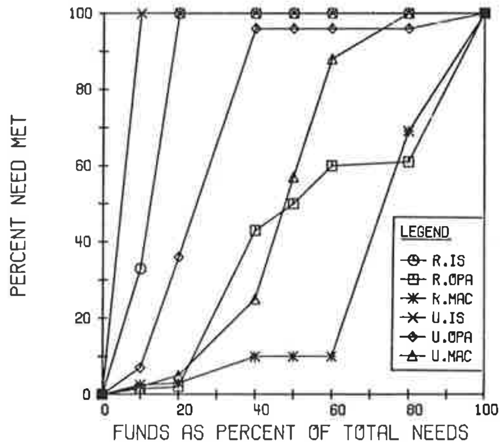
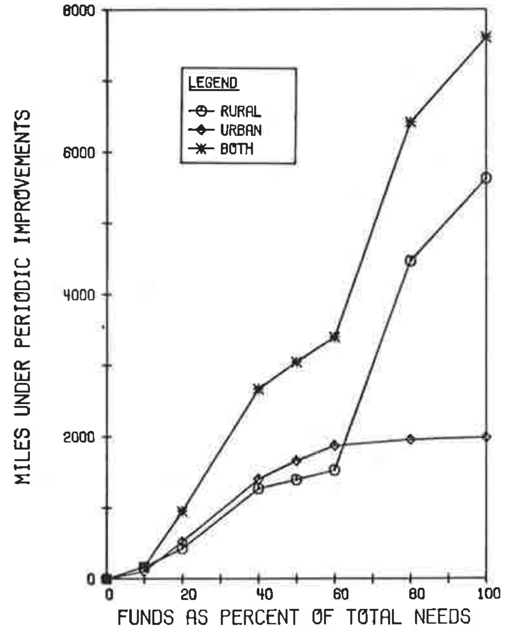


Figure 3. Impact of funding level on miles of periodic improvement.



economic scenarios, it is necessary to keep funding levels constant across scenarios. It was found that an average yearly amount of $510 million of federal funds and $150 million of state funds were needed to fulfill Indiana's total estimated need during 1976 to 1985. This estimate was obtained by running the model without any budget constraints. Based on this estimate, a medium funding level of 50 percent of estimated need was assumed. Thus, a federal funding of $255 million and a state funding of $75 million per year were assumed for these scenarios.

DISCUSSION OF RESULTS

The results of analyzing the several scenarios are briefly presented in this section. As an example problem, the various policy and funding scenarios applied to one state and one cycle are given.

Fund Allocation Among Highway Classes

The optimal strategy in terms of the percentage needed to be met in each highway class at different funding level scenarios ranging from 20 percent to 100 percent of estimated capital needs is shown in Figure 2. The interstates (rural and urban), which are heavily used facilities, draw all their needs even when funding equivalent to only 20 percent of the total system's need is available. Different classes receive their full needs at different points, rural other principal arterials, and rural minor arterials and collectors are the last to receive full needs.

This figure can be useful in deciding on deferred maintenance. At the 20 percent level all highways other than interstates have a bulk of their maintenance deferred; the rural minor arterials and collectors will have to forego 90 percent of their maintenance unless 60 percent of the needed funds as estimated become available.

This graph, however, is applicable only for the policy scenarios considered (proportion of state funds to federal funds, relative importance of system objectives, minimum tolerable conditions, etc.). If one or more of these factors changes, another series of model runs must be made to generate corresponding information.

Miles Under Periodic Improvement

The miles chosen for periodic improvement under different levels of funding are presented in Figure 3. Urban highways get more miles improved at lower funding levels of investment. Beyond the 60 percent level, as urban highway needs are almost fulfilled, the increased money is used for rural highways. Because the average unit cost of rural highways is much less than that of urban highways, a lot more rural mileages could be improved.

It can also be concluded that between the 40 percent and 60 percent investment levels, there is no significant increase in the miles covered by periodic improvement. Even after the 60 percent level, the additional activity is all in minor widening of rural minor arterial. Hence, it may be concluded that under the given scenarios it is just as good to invest 40 percent of the estimated need and still fulfill most of the improvement needs in higher highway classes, as it is to spend 100 percent of the estimated needs.

Overall Achievement Index

As mathematical optimization is used, "optimum" is measured by the value of the objective function (see Equation 8). The value of this function can range from zero, obtainable when all the targets are achieved, to a maximum value when no activity is undertaken. This maximum value, Z^*_{max}, can be easily computed by substituting T_{kh} for each d_{kh} in Equation 8. Denoting the value of the objective function printed out by the optimization module by Z^*, an index of overall achievement can be computed as

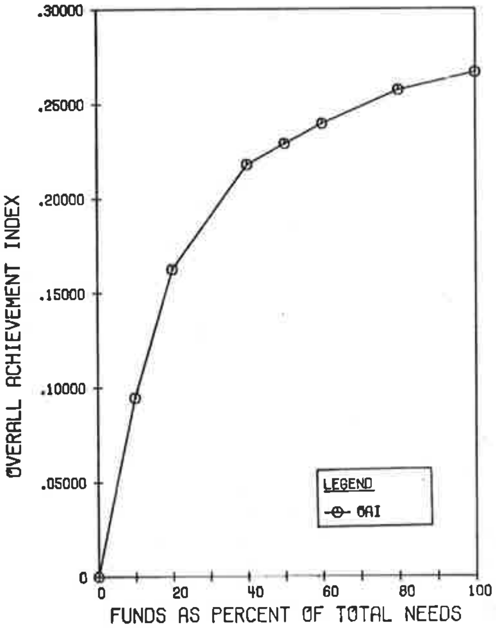
$$\mathrm{OAI} = {}^{Z^*}\mathrm{max}^{-Z^*}/\,{}^{Z^*}\mathrm{max} \qquad (9)$$

A value of zero for OAI indicates no improvement and a value of 1 indicates complete success in terms of achieving the set targets. The values of OAI at different funding levels are shown in Figure 4. It is interesting to note that there is a decreasing marginal return on investment, and beyond the 40 percent level there is no significant improvement.

Effects of Funding Policy

The policy of non-categorical funding is compared with the policy of restricting federal funds to capital improvement projects. Table 1 gives comparative values for these two scenarios in terms of total amount spent, total miles affected, and percentage of needs met. Only those class-activity combinations that are sensitive to this policy change are shown in Table 1. It is seen that non-categorical funding (scenario 2) shifts the optimal strategy heavily toward minor widening of urban minor arterials and collectors and away from safety and traffic engineering improvements in this class of roads as well as rural other principal arterials. From this, it can be inferred that it is preferable to carry out minor widening in urban minor arterials and collectors to reach the stated objective; the imposition of restrictions in the form of categorical funding policies forces the selection of safety and traffic engineering improvement and thus a suboptimal strategy. It may be recalled that safety and traffic engineering improvements are eligible for 90 percent federal funding while minor widening gets only 75 percent, which explains the heavy bias toward the former activity under scenario 1 (categorical funding).

Figure 4. Overall achievement at different funding levels.



It is also worth noting that the extent to which safety and traffic engineering was selected under non-categorical funding was the minimum imposed by equity constraints--namely, 1 percent of the identified need.

Thus the trade-off implied in alternative policy scenarios is also brought out by this model. The results in Table 1 are at 50 percent funding, and the trade-off might differ in type, extent, or both, at other funding levels.

Effects of Varying Relative Importance of System Objectives

The above analyses used a set of weights to reflect the relative importance given to system objectives within a highway class as well as across highway classes. The results of the optimization problem are sensitive to these weights, and a change in one or more of these weights would result in a different strategy of highway system preservation. Such a change in weight could be needed, for example, if one system objective is considered more important than indicated by the present weighting system. Also, the imposition of relative weights implies some tradeoff among highway classes and activities. These weights are in the nature of policy options inasmuch as they are specified by policymakers. To analyze these effects the last discussed model of a non-categorical option was run specifying equal (unit) weights for all system objectives and all classes.

The most significant results of the equal-weights scenario and the non-categorical differential weight scenario are shown in Table 2. It is seen that urban minor arterials and collectors get still more minor widening and have a value to 98 percent of the required amount. This time, the losers are urban other principal arterials, where safety improvement is reduced to the bare minimum of 1 percent. Thus,

Table 1. Comparison of alternative funding policies: categorical versus noncategorical.

		Total Funds Spent ($000s)		Miles Improved		Needs Met (%)	
		Scenario		Scenario		Scenario	
Highway	Activity	1	2	1	2	1	2
Rural other principal arterials	Safety and traffic engineering	16 817	1 318	112	9	13	1
Urban minor arterials and collectors	Minor widening	128 961	208 049	247	398	45	73
	Safety and traffic engineering	64 231	641	584	6	100	1

Table 2. Effect of varying relative weights for system objectives.

		Total Funds Spent ($000s)		Miles Improved		Needs Met (%)	
		Scenario		Scenario		Scenario	
Class	Activity	2	2-EW[a]	2	2-EW[a]	2	2-EW[a]
Urban other principal arterials	Safety and traffic engineering	70 269	795	234	3	88	1
Urban minor arterials and collectors	Minor widening	208 049	277 525	398	531	73	98

[a] 2-EW refers to scenario 2 with equal weights.

Table 3. Miles requiring various activities: Indiana, 1988-1989.

	Scenario		
Activity Type	3	4	5
Routine maintenance	31 951	31 953	31 951
Resurfacing	1 412	1 489	1 412
Other periodic improvements	7 615	7 063	7 655
All periodic improvements	9 027	8 557	9 067
All activities	40 978	40 510	41 018

the trade-off is between these two activity-highway class combinations.

IMPACT OF MACROECONOMIC FUTURES AND THEIR IMPLICATIONS FOR INDIANA HIGHWAY SYSTEM

In order to study the impact of alternative futures, the current highway system needs to be the starting point. But, the latest available systemwide data are those for 1975 as given in the NHIPS (4). Hence, the current system (1981) was generated by applying the model to the 1975 system and iterating through three cycles of two years each. The amount of money spent in highway activities in Indiana from 1974 to 1978 was estimated from Table HF-2 of Highway Statistics (1975 to 1979). This table gives the disbursements for capital outlay and maintenance activities in each state from all units of government. This information was broken down into capital expenditure met from federal and state funds, respectively. The maintenance expenditure shown in Table HF-2 of Highway Statistics includes operation, administration, and other activities such as snow removal, litter removal, grass mowing, and others that are not included in the routine maintenance activity as defined in this study. The expenditure on routine maintenance as defined here was found to be about 25 percent of the total maintenance expenditure by the State of Indiana during 1975 and 1979. Hence, 25 percent of the figure reported in Table HF-2, was added to the state share of capital outlay to give the total highway expenditure by the state. The budget figures thus derived were $94 371 000 of federal funding and $91 064 000 of state money per year.

Then, starting with the updated system of 1981 as a base, the three macroeconomic futures were tested. The discussion can be detailed for each cycle. However, for brevity, only the results that correspond to the period 1988-1989 are presented here.

Improvement and Maintenance Needs

The table below summarizes the improvement needs at the beginning of year 1982:

Activity Type	Miles
Routine maintenance	31 283
Resurfacing	1 143
Other periodic improvements	6 462
All periodic improvements	7 605
All activities	38 888

This summary can, however, be provided in greater detail if needed. The figure tabulated as miles under all activities is in excess of the total system length of 31 283 miles. This reflects the fact that there are sections of highways deficient in more than one attribute, thus necessitating that more than one activity be undertaken. The need, then, is expressed in terms of deficiency miles.

The summary of identified needs in 1988-1989 in each of the scenarios is given in Table 3. Scenario 4, one of slower growth in vehicle travel, has resulted in fewer miles of wear and tear and, hence, needs less improvement activity.

Scenario 5 combines faster traffic growth with faster increase in cost and results in maximum improvement need. Thus, the need for all improvements in the year 1988 could range from 8613 miles to 9067 miles depending on the macroeconomic and policy climate, as well as cost-revenue trends.

The need in terms of miles requiring various activities at the beginning of the analysis will be identical under the three scenarios. As the analysis proceeds, however, the rate of deterioration during each cycle will differ among scenarios. This results in a different set of feasible activities for each scenario in any cycle other than the first one. The difference in supply of highway funds among the scenarios results in a different optimal strategy. The cumulative effect of this interaction between varying rates of deterioration and optimal strategy is the cause for differences in the figures for each scenario in Table 3.

System Performance

Another practical use of this model lies in its capability to give a system summary at any point in the analysis. A system summary as required up to any predetermined point can be printed. For reasons of economy, summaries at the end of the fourth cycle are tabulated for each scenario. Table 4 gives the summary in terms of the percentage of miles under various levels of deficiency in each attribute at the end of year 1989 for scenario 1. Table 5 summarizes the same information in terms of improvement scores.

APPLICATION IN HIGHWAY PROGRAMMING

The model can be used in developing a strategic program for state highways in terms of apportionment of funds from different sources on different activity-highway class combinations. The report-generating program prints tables summarizing the optimal strategy. From these tables, questions on fund utilization strategy for each cycle and at any desired level of aggregation (all rural, or all interstates, or all improvement activity) can be answered.

The best distribution of estimated state funds for the last cycle (1988-1989), given by the optimization program, is shown in Table 6. These figures could be considered as the estimated share of various activity-class combinations under the given level of funding and the given set of system objectives.

The question of what activities are best deferred is answered in Table 7 for the period 1988-1989. It is seen that although the answer depends on the scenario, deferring periodic improvement other than resurfacing is, in general, advisable.

CONCLUSIONS

A major challenge to transportation agencies throughout the country today is how to maintain and preserve the extensive network of highway facilities in the face of competing needs for public money, increasing costs, and inflationary effects. Therefore, there is a need to develop a methodology to allocate limited financial resources for highway system improvement and maintenance.

This paper discussed the development of a model to apply goal programming techniques to the multiobjective decision problem of highway system maintenance. The use of this approach has been illus-

Table 4. Summary of state performance: Indiana, scenario 3, 1983.

		Rural			Urban		
Attribute	Rating	Interstate	Other Principal Arterials	Minor Arterials Collectors	Interstate	Other Principal Arterials	Minor Arterials Collectors
Pavement type	Unpaved	0	0	14.00	0	0	0
	Low	0	0	6.00	0	0	4.00
	Intermediate	0	0	48.00	0	0	62.00
	High	100.00	100.00	32.00	100.00	100.00	34.00
Pavement condition	Poor	0	4.00	8.00	0	24.00	2.00
	Fair	12.00	92.00	66.00	32.00	72.00	64.00
	Good	88.00	4.00	26.00	68.00	4.00	34.00
V/C ratio	Poor	4.00	4.00	0	22.00	23.00	20.00
	Fair	50.00	30.00	22.00	58.00	49.00	36.00
	Good	46.00	66.00	78.00	20.00	24.00	44.00
Peak-hour operating speed	Poor	0	0	2.00	0	99.99	99.99
	Fair	0	44.00	56.00	16.00	99.99	99.99
	Good	100.00	56.00	42.00	84.00	99.99	99.99
Lane width	Poor	0	0	24.00	0	2.00	12.00
	Fair	0	12.00	62.00	0	18.00	52.00
	Good	100.00	88.00	14.00	100.00	80.00	36.00
Right shoulder width	Poor	0	34.00	70.00	0	38.00	68.00
	Fair	0	26.00	28.00	0	22.00	22.00
	Good	100.00	40.00	2.00	100.00	40.00	10.00
Length (miles)		905	1293	22 255	274	1552	4221
ADT (vehicles 000s)		14.49	4.72	1.16	38.89	12.92	4.63

Note: 99.99 is printed when an attribute is not applicable for that class of highway.

Table 5. Summary of performance indices: Indiana, scenario 3, 1983.

	Rural			Urban		
Attribute	Interstate	Other Principal Arterials	Minor Arterials Collectors	Interstate	Other Principal Arterials	Minor Arterials Collectors
Pavement type	4.00	4.00	2.98	4.00	4.00	3.30
Pavement condition	2.88	2.00	2.18	2.68	1.80	2.32
V/C ratio	2.42	2.62	2.78	1.98	1.96	2.24
Peak-hour operating speed	3.00	2.56	2.40	2.84	99.99	99.99
Lane width	3.00	2.88	1.90	3.00	2.78	2.24
Right shoulder width	3.00	2.06	1.32	3.00	2.02	1.42

Note: 99.99 is printed when an attribute is not applicable for that class of highway.

Table 6. Strategy for use of state funds: Indiana, scenario 5, 1988-1989.

Highway Class	Routine Maintenance ($000s)	Periodic Improvement ($000s)	Total ($000s)
Rural interstate	1 373	12 640	14 013
Rural other principal arterials	1 150	1 589	2 739
Rural minor arterials and collectors	9 336	841	10 177
Urban interstate	870	18 129	18 999
Urban other principal arterials	2 522	79 901	82 423
Urban minor arterials and collectors	3 445	3 897	7 342
All	18 696	116 997	135 693

Table 7. Deferred activities: percentage of need, 1982-1983 miles.

	Scenario		
Activity Type	1	2	3
Routine maintenance	nil	nil	nil
Resurfacing	nil	nil	nil
Other periodic improvements	5784	5784	5922
All periodic improvements	5784	5784	5922

trated by an example based on the Indiana highway system. The experience of the research at this point is encouraging and confirms the suitability of this approach to highway system programming and management. The overall highway system analysis methodology being developed will enable decision-makers to address various issues such as trade-offs among system objectives, among highway classes, and among activity types. It is also possible to analyze the impacts of different policy decisions on the needs and performance of highway systems.

ACKNOWLEDGMENT

The research was conducted with financial support from the Research and Special Projects Administration of the U.S. Department of Transportation. However, we are solely responsible for the results and the opinions expressed.

REFERENCES

1. M. Muthusubramanyam and K.C. Sinha. Highway System Performance Analysis and Optimal Allocation of Funds in a Region: A Case Study. Automotive Transportation Center, Purdue Univ., West Lafayette, IN, June 1981.

2. K.C. Sinha, A. Ravindran, and M. Muthusubramanyam. A Model for Optimal Maintenance of Highway Systems Under Resource Constraints. U.S. Department of Transportation, Rept. DOT-ATC-79-7, Aug. 1979.
3. M. Muthusubramanyam. Highway Improvement and Preservation Under Limited Financial Resources--An Application of Multi-Objective Optimization. School of Civil Engineering, Purdue Univ., W. Lafayette, IN, Ph.D. dissertation, Dec. 1981.
4. National Highway Inventory and Performance Summary. Federal Highway Administration, FHWA-PL-78-006, 1976.
5. J.P. Ignizio. An Introduction to Goal Programming with Appplications in Urban Systems. Computers, Environment and Urban Systems, Vol. 5, 1980, pp. 15-33.
6. S.M. Lee. Goal Programming for Decision Analysis. Averbach Publishing, Philadelphia, 1972.
7. The Status of the Nation's Highways: Conditions and Performance. Committee on Public Works and Transportation, U.S. Congress, Rept. 95-29, Sept. 1977.
8. Alternative Futures for Southeastern Wisconsin. Southeastern Wisconsin Regional Planning Commission, Milwaukee, 1980.
9. F.L. Mannering. Methodology for Evaluating the Impacts of Energy, National Economy, and Public Policies on Highway Financing and Performance. Purdue Univ., West Lafayette, IN, Rept. JHRP-79-6, July 1979.

Abridgment

Methods for Identifying Transportation Alternatives

MICHAEL NELSON AND DANIEL BRAND

This paper describes a four-step alternatives generation methodology for use in urban transportation planning. The four steps are (a) assess costs of any contemplated high-capital transit alternatives using locale-specific descriptors and apply capital cost feasibility tests, (b) identify generic alternatives that are responsive in the local context, (c) generate responsive site-specific configurations of selected generic alternatives, and (d) test for operational feasibility to ensure internally consistent and workable alternatives for later analysis. Overall, the process combines efficiency, ease of use, and responsiveness of output to produce alternatives for the planning process. The four steps are designed to minimize the information output and testing necessary for producing a responsive set of alternatives. These alternatives are described in sufficient detail so that they may be distinguished by their expected impacts, on the basis of which appointed and elected officials and the public will eventually make decisions.

Historically, transportation planning has lacked a rigorous methodology for proceeding from goals to specific alternatives. For the most part, alternatives appear to be a direct product of the planner's imagination. This does not assure alternatives that encompass the most cost-effective trade-offs in goal achievement. This lack of methodology is a serious problem because multibillion dollar investment decisions depend ultimately on the credibility of the generation process.

Fortunately, there are relatively few design principles to which an alternatives generation method must adhere. The first design "imperative" is that (a) the amount of money allocated to transit investments and projects cannot exceed available local and federal funding resources. Subordinate to this cost feasibility test is that (b) additional benefits commensurate with the additional cost of an alternative must be potentially realizable at the alternatives generation stage. Finally, from an engineering point of view, a third design principle exists--namely, to confirm these costs and benefits (c) alternatives must be tested to ensure that they are internally consistent and workable (i.e., operationally feasible). These three design principles lead to three distinct types of tests in a process of generating transportation alternatives that are politically, economically, and technologically relevant to the locale--cost-feasibility, cost effectiveness (additional net benefit commensurate with additional cost), and operational feasibility.

The proper ordering of these tests depends primarily on their information requirements. For economy of study effort, tests that require little information for their application should occur early in the process, while those that require detailed information should come later. In general, the detail required for application of these tests in developing and screening alternatives increases in the same order (a,b,c) as they were presented. Preliminary cost estimates can often be made on the basis of relatively few descriptors, while operational feasibility tests may require substantial engineering detail (e.g., operating plans are required to evaluate feasible headways and operating speeds). Cost-effectiveness assessments fall somewhere in the middle, requiring enough information to cover costs and a range of other impacts without considering detailed operation.

Based on these considerations, a four-step alternatives generation methodology has been developed. Each of the four steps is described below.

STEP 1: ASSESS COSTS OF CONTEMPLATED HIGH-CAPITAL TRANSIT ALTERNATIVES

Step 1 is designed to eliminate high-capital transit alternatives from further consideration if they are not financially feasible at the local and federal levels. The generic alternatives that should be articulated in step 1 are only those high-capital alternatives that the local area has a political predisposition toward, or which local and/or federal planners or planning requirements suggest should be studied as a set (e.g., if rail, then also express bus).

The approach recommended for assessing costs is based on the decision tree type of structure. Given a generic alternative (e.g., light rail, busway, etc.), sequential consideration of the descriptors needed to define it for cost estimation allows a comprehensive and efficient determination to be made of the configurations that are worthy of further analysis. The process begins in the given (a) corridor of interest for the given (b) generic alternatives of interest. The specification of these two descriptors emerges from the regional 3C planning process and local political and institutional factors.

These two descriptors begin the series of descriptors for each alternative that must be specified. Cost descriptors of high-capital alternatives include corridor; generic alternative--wheel/guideway technology, guidance and control, development risk; segment length; extension of existing technology; previous use of right-of-way; map-based alignment; vertical alignment; major new construction involved; number of stations; and station parking.

The specification of these descriptors is made on the basis of relevance, local conditions, and attainment of goals.

1. Relevance of Descriptors--Certain descriptor values are not relevant to or consistent with given generic alternatives. For example, heavy rail "generically" uses steel wheels on steel rails and has many past applications, so no other possible values for "wheel/guideway technology" and "development risk" need be considered in the heavy rail branches of the tree.
2. Local Conditions--Descriptor values that generally are possible for a generic alternative may be impractical for site-specific reasons. For example, in a dense downtown area it may not be practical to place fixed-guideway systems at grade. Another example is if an alternative is an extension of an existing fixed guideway, one end of the map-based alignment is fixed.
3. Attainment of Goals--Both cost minimization and attainment of other goals through development of responsive alternatives are referred to here. Cost minimization is a clear goal and can be implemented by using information on the costs associated with different descriptor values. Generic alternatives should be designed fairly modestly so as not to rule them out prematurely on a cost basis.

Each tree-building process for each generic alternative in a particular corridor may result in one to possibly five or more fully described alternatives. Multiple alternatives result from branching, most likely on the value of segment length and map-based alignment. Single values of most of the other descriptors normally follow from engineering considerations.

After each "articulation" of each high-interest, high-capital generic alternative has been costed, it must be subjected to cost feasibility tests. The capital costs of each are matched against available dollars from a variety of local, state, and federal funding sources to determine cost feasibility. Some early and realistic assessments of the political feasibility of raising money from each potential source must be made.

At the end of the three relatively distinct procedures in Step 1, three important products emerge:

1. A set of high-capital transit alternatives that appear at least feasible from a capital cost point of view,
2. Important site-specific information on these high-capital alternatives, and
3. A preliminary sense of the non-cost-related goals that motivate consideration of these remaining high-capital transit alternatives.

These three products of step 1 form highly important input to the next step in alternatives generation.

STEP 2: IDENTIFY GENERIC ALTERNATIVES RESPONSIVE IN LOCAL CONTEXT

Step 2 is a decision table method that allows explicit and documented use of a range of local and national goals to produce a small set of the most responsive generic alternatives for local conditions. It achieves this by eliminating information at the descriptor level entirely and by defining site-specific (e.g., corridor) goal achievement as a result only of the named generic alternative. A large set of alternatives can therefore be eliminated on the basis of a very limited amount of technical analysis. Step 2 uses as input the non-eliminated high-capital alternatives from step 1, as well as all other possible (low-capital) technological, operational, and regulatory alternatives. It is important to distinguish at this stage that the result of step 2 is not a set of site-specific configurations of alternatives. Site-specific detail is left to step 3.

The number of alternatives that are available for input to step 2 may be very large. At least 74 generic alternatives have been identified that should be considered at least implicitly in the process of alternatives generation (1). Although consideration of a comprehensive set of alternatives in the alternatives generation process imposes some practical problems, it is essential if the process is to produce valid results. This is due to the fact that if the set of alternatives under examination does not include the most productive ones available, no amount of refinement through sophisticated impact forecasting techniques and/or community participation can produce the most cost-effective possible solution.

The key to step 2 is the production and use of a table or matrix relating potentially attainable goal achievement results to individual generic alternatives. Because expected results will vary depending on site-specific factors, the matrix should contain ranges of possible goal attainment. The elements of the matrix therefore consist of high and low "scores" for each alternative in each goal area.

It is recommended that the table of site-specific goal attainment for each generic alternative be developed by using a "delphi-type" technique to incorporate the opinions of several transportation professionals. This approach uses an iterative framework whereby the opinions of individuals may change over time as the merits of different hypotheses are tested, eventually resulting in group consensus. The table can be improved on the basis of studies of previous implementations, demonstrations, etc. In this manner, the accumulated experience concerning transportation systems effects can be explicitly brought to bear on the alternatives generation process. [A multistep process of delphi evaluation was used successfully in the Priority Engineering and Operational Analysis (October 1976), part of the Miami alternatives analysis process. That study used the delphi method to estimate goal attainment for 30 alternatives (heavy or light rail in different configurations). Weights on different goals that were at least partially derived through direct citizen participation were then applied to find preferred alternatives.]

Given the production of a table relating goal attainment in the local context to the available generic alternatives, the process by which locally responsive alternatives are identified is quite simple and works as follows. First, it must be seen if there are alternatives that are totally dominated (i.e., best score on all measures of goal achievement is worse than some other alternative's worse scores). However, given the presence of a significant number of goals, dominance of this type is not likely to permit elimination of many alternatives from consideration at this point. In order to further reduce the set of alternatives, importance weights are applied to each of the goals relevant to the local setting. A variety of methods exist for determining such weights, including direct provision by the decisionmaker, analysis of trade-offs in goal attainment articulated as being desirable by the decisionmaker, and other utility assessment techniques. Weights uncovered in public participation, monetized values of the impacts, local priorities exhibited through previous expenditures to attain comparable ends, etc. should also be related to the weights actually used wherever possible.

For each alternative, the weights on each goal are applied to the appropriate entries in each cell for each alternative yielding "high" and "low" total scores. There will be at least one alternative for which the high total score is a maximum for all alternatives. This alternative becomes the standard against which all alternatives must be compared (i.e., the "current optimum"). If the high score of any alternative does not exceed the low score of the current optimum, it can be concluded that the alternative in question does not have any reasonable potential of meeting the goals relevant in the application setting better than the current optimum, and, therefore, does not warrant further analysis.

Overall, this second step in the process of transportation alternatives generation has several benefits.

1. It comprehensively considers all the possible effects of all the possible alternatives in a given local context. It therefore avoids the possibility of "missing" responsive alternatives.
2. It does not require the use of expensive assessment methodologies. Local information is input only as needed.
3. It makes the greatest possible use of past experience. Although the matrix elements are initially filled in on the basis of professional judgment, they are subject to modification and improvement on the basis of studies of previous implementations, demonstrations, etc.
4. It is not overly prescriptive because a local area can consider the widest possible range of cost-feasible alternatives that are of local interest.
5. The process is easily documented to respond to government requirements in the form of the goal attainment tables developed and used, the goal weights used, and the resulting goal attainment scores used to screen alternatives (also at successive iterations, if required).

STEP 3: GENERATE RESPONSIVE SITE-SPECIFIC CONFIGURATIONS OF SELECTED GENERIC ALTERNATIVES

Step 3 is a decision tree method that details all of the alternatives emerging from step 2 to maximize their contribution to the goals propelling their consideration. The output of step 3 for each alternative is a set of values for all of the descriptors needed for impact estimation and operational feasibility testing. While there may be a temptation to articulate alternatives in more detail so that they become more "real," the principal consideration must be to reduce the information load to the minimum amount necessary to discriminate between alternatives with respect to their expected impacts of interest at any step of the alternatives generation or evaluation process. The decision tree process for "fleshing out" generic alternatives in a given environment works as follows:

1. Select a descriptor;
2. Test for generic restrictions;
3. Test for site-specific restrictions;
4. By using all available information, test for goal attainment; and
5. If different values for the descriptor are still possible, add a set of branches to the decision tree corresponding to the different choices.

An ordering of descriptors that has been found to be successful for the most complicated high-capital alternatives is the following (corridor and generic alternatives are given):

wheel/guideway technology
guidance and control
development risk
routing policy
roadway use regulations
activity policy type
length
extension of existing technology
previous use of right-of-way
map-based alignment
vertical alignment
major new construction involved
scheduling policy
number of vehicles
vehicular capacity
distance between stations
number of stations
on/off-line stations
station parking
bus feeder provided
passenger protection from environment
passenger access to adjacent buildings
traffic separation
transfer-related factors
maintenance facilities
organization running operation
labor requirements
fare structure
average travel speed
average wait time

Note that some descriptors near the top of the list are seemingly less important than subsequent ones. This occurs because single values can generally be specified for each of these descriptors solely on the basis of the generic alternative. In this manner, they can be dealt with efficiently and gotten out of the way early in the process. In the event a lower-level descriptor significantly changes the goal achievement of an already selected higher-level descriptor value, the user should reassess the design beginning with the higher-level descriptor. Clearly, the ordering that is chosen will have an important effect on the efficiency of this process. There is no way to order the descriptors so that information generated lower in the tree never affects goal attainment higher in the tree for every possible generic alternative. A saving grace in this regard is that the great majority of low-capital generic alternatives is likely to involve a relatively small number of descriptors.

STEP 4: TEST FOR OPERATIONAL FEASIBILITY

The operational feasibility tests in step 4 represent a further progression in the process of selecting detailed descriptor values. That is, given a set of fully described and responsive alternatives that do not exceed cost limitations, it is necessary to ensure that they are internally consistent and workable before further analysis is warranted. At this alternatives generation stage, these tests should be based largely on intuition and hardware feasibility (e.g., headway capabilities). Operational feasibility tests should also concern aspects of the application setting (e.g., intensity of land use) as they affect descriptors of alternatives (e.g., station spacing). A detailed description of the operational feasibility tests that are appropriate for generation and other stages of analysis is, unfortunately, precluded by space limitations.

CONCLUSION

It is neither possible nor desirable to fully articulate prescribed courses of action in all possible scenarios. However, the described method has both the flexibility to incorporate site-specific conditions and goals and the power to guide the process of describing alternatives in detail. The result is a set of responsive configurations of generic alternatives described in the detail required for impact prediction appropriate to the current stage of local planning.

ACKNOWLEDGMENT

The material presented in this paper is drawn from the results of a study funded by the U.S. Department of Transportation. However, the opinions and conclusions expressed or implied in this paper are ours, and we are solely responsible for any errors of content or omission that remain.

REFERENCE

1. Generation of Transportation Alternatives. Prepared for U.S. Department of Transportation; Charles River Associates, Inc., Boston, MA, Jan. 1979.

Abridgment

Highway Program Performance Monitoring at PennDOT: An Overview

THEODORE H. POISTER

An approach to developing a performance monitoring system is presented and illustrated with work conducted for the Pennsylvania Department of Transportation. A systems model is used to specify the logic underlying the Department's highway programs, and data sources and sets of performance indicators are developed to operationalize various aspects of the model. The measures reflect both efficiency and effectiveness criteria and are based as much as possible on existing data bases. Where necessary, new data sources, such as a road condition survey and a citizen survey, have been developed.

An integral part of the thrust toward improved management direction and control of state transportation programs is performance monitoring--i.e., developing systematic and periodic information on the progress and outcomes of program activities. This type of information feedback can be used to assess program effectiveness and to identify necessary improvements. One report on monitoring the effectiveness of state transportation services suggests several uses of this information: (a) review of progress and trends in the provision of transportation services, (b) provision of guidance for resource allocation decisions, (c) budget formulation and justification, (d) in-depth program evaluation and program analysis, (e) encouragement of employee motivation, (f) assessment of the performance of contractors, (g) provision of quality control checks on efficiency measurements, and (h) improved communication between citizens and government officials (1).

This paper outlines the development of performance indicators for the highway programs of the Pennsylvania Department of Transportation (PennDOT) and presents a conceptual base and analytical approach that can be applied by other departments of transportation and in other program areas. The primary purpose was to provide various levels of management with information to help them operate programs more effectively. Second, stemming from the report-card concept proposed by the earlier fiscal review (2), the indicators are designed to communicate selected key indicators to external audiences, such as the legislature, the Governor's Budget Office, and the public, to document the Department's track record.

Performance monitoring systems consist of three basic components: a data collection component, a processing and analysis component, and an action component (3). The basic approach to developing a monitoring system proceeds through the following five steps: (a) identify the program's objectives and outline the program design, (b) determine what kinds of measures would be most suitable as performance indicators, (c) identify potential data sources within and outside the Department and assess their quality and appropriateness, (d) begin data processing and/or reformatting to obtain initial output and assess the appropriateness and workability of those particular indicators, and (e) refine these data elements and develop the overall performance monitoring system in terms of data processing, frequency of reporting, channels of communication, and intended use. The primary strategy employed was to rely on existing departmental data bases as much as possible. State transportation departments generate vast quantities of data and typically maintain many large record keeping systems, but often there are few linkages among them. Part of the effort lies in evaluating the potential worth of existing data sources and ways of improving the use of information they contain. Where necessary, however, new data-collection procedures have been devised, as discussed below. The development and evaluation of specific measures was based on the following considerations: (a) reliability--how dependable and consistent are the procedures for collecting data; (b) validity--how accurately and directly does the proposed measure represent that aspect of performance being examined; and (c) sensitivity--how responsive is the measurement scale to what may be small but real changes in actual performance (4)?

OVERVIEW OF PROGRAM LOGIC

The design of the performance monitoring system stresses the importance of end results, and thus indicators of effectiveness (i.e., Are programs achieving their objectives?) are of central concern, as well as the more customary "process" measures concerned with efficiency. Figure 1 outlines the logic of the Department's overall highway program, including the three major components: maintenance, highway construction, and safety construction. The

Figure 1. Overview of highway program performance monitoring.

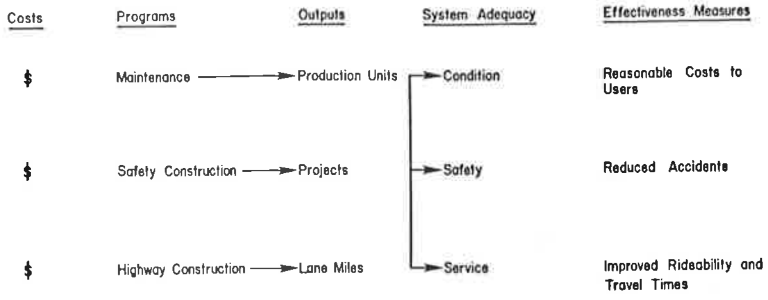
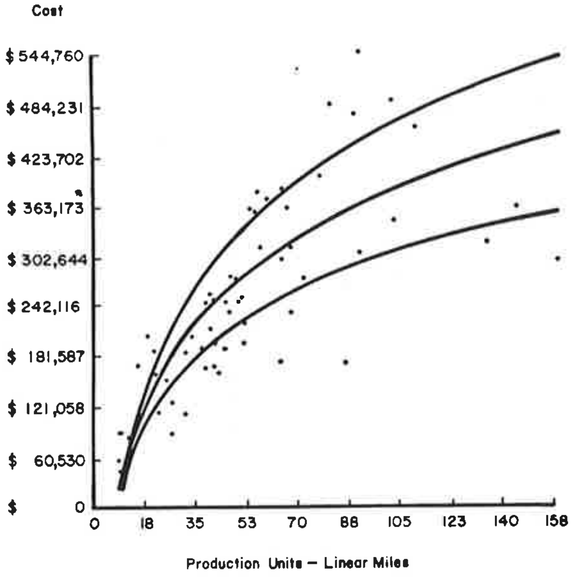


Figure 2. Surface treatment cost by production level.



Upper and lower curves show ±20% from average cost based on production. Production units in tons (for plant mix) and gallons (liquid bituminous) have been converted to linear miles.

inputs to these programs are manpower, materials, equipment, and contract services, which are represented in Figure 1 as dollar costs. Their most direct products are termed outputs. PennDOT defines production units for measuring the amount of output for its maintenance activities, such as lane miles treated or feet of guardrail replaced. The output for the highway construction program can be measured by linear miles or lane miles of new construction. Because the safety construction program includes many different types of projects, it would require varied indicators of output.

The combined effect of the outputs produced by the maintenance and construction programs should be improvement of the quality of the state's highway system. This improved quality, or system adequacy, is not really an end in itself, but rather a necessary step toward the goal of fast, safe, and efficient highway transportation for its users. Road system quality has traditionally been evaluated with sufficiency ratings based on an assessment of three categories of highway features: condition, safety, and service. There is not a one-to-one relation among the three programs and their respective outputs within these three rating categories, although there is some degree of correspondence as represented by the parallel lines in Figure 1. Thus, condition of the roads would depend primarily on the maintenance program; safety features would depend primarily on safety construction projects; and service aspects of the road system would depend mainly on the highway construction program. However, there are direct relations that cross over these lines, and, in particular, it should be noted that the maintenance program actually impacts on all three rating categories.

Given the overall objective of fast, safe, and efficient highway transportation, the most straightforward measures of effectiveness would relate to the costs incurred by users, accident rates, and travel times. As before, there are no unique one-to-one relations between the three sufficiency rating categories and the three types of effectiveness measures. Safety features, for example, will impact on user costs and travel time as well as on accident rates. Yet, user costs might be expected to depend primarily on road conditions, while accident rates would depend on safety features, and travel times mainly on service levels.

PROCESS MONITORING

Tracking the implementation of programs and the activities to carry them out is called process monitoring. Although these measures do not directly represent outcomes, process monitoring is important because it provides an indication of the quantity and quality of the work completed. PennDOT has established a Management Objectives Report, which presents basic data on personnel complements, expenditures, and activities together in one place on a monthly basis. This report, which compares actual to planned or budgeted amounts per month and cumulative figures with comparable data for the previous year, allows top management to track the progress of organizational divisions and programs in terms of outputs--i.e., how much work has been accomplished.

Developing indicators of maintenance program efficiency was facilitated by the fact that PennDOT already had a good start on a monitoring system with its Highway Maintenance Management System (HMMS), a computerized information system for programming and tracking the internal operation of maintenance activities. For the whole set of specific work activities or cost functions that make up these programs, HMMS reports monthly data on manpower, materials, and equipment costs as production on a county-by-county basis. The outputs, or production units, ideally would be measured in terms of both quantity and quality, but quality indicators are not available at present. The most direct measure of efficiency, disregarding quality, is the unit cost such as the cost per ton of manual patching completed or the cost per mile of shoulder cutting completed. Such unit cost data can be monitored over time and compared across districts and counties. Figure 2, for example, shows a semilog regression of the cost of surface treatment on production units; cost increases with production but at a diminishing rate due to economies of scale. The figure also shows a "tolerance band" within ±20 percent of predicted cost in order to identify those counties (falling outside the band) that appear to be the most and least efficient in their surface treatment operations.

LINKING VARIABLES: SYSTEM ADEQUACY

As indicated above, the intended linkages between program outputs and real effects are represented by measures of system adequacy, running the full gamut of observable changes in the physical design and condition of the roads. Whereas data on the design-related features were readily available, systematic feedback was not being generated on many of the more variable conditions or service features. Therefore, a major effort in the development of performance indicators was to develop and test a road condition survey by using trained observers. As with a somewhat similar survey in Ohio (5), these trained observers physically inspect the roadway and record the frequency of "reportable conditions" on a sample of highway segments in each county on a periodic basis.

The design and preliminary results of this trained observer survey have been reported elsewhere (6). The initial cycle taken in the fall of 1979 showed very widespread variation in most of the reportable conditions, with some systematic association with maintenance functional category (MFC). In contrast to many other condition surveys, the primary purpose of the Pennsylvania trained-observer survey was to permit an aggregate monitoring of condition over time. For example, Table 1 shows changes in the mean counts of major cracking by maintenance functional category over the first five cycles of the survey. The incidence of major cracking dropped substantially across the first four cycles and then increased somewhat by cycle 5 for a net reduction of roughly 60 to 80 percent on the various MFCs. This reflects a major improvement in surface condition resulting from base repair, skin patching, and crack sealing activities.

Table 1. Trained observer survey: major cracking counts per mile.

Maintenance Functional Category	Cycle 1 (Fall 1979)	Cycle 2 (Spring 1980)	Cycle 3 (Fall 1980)	Cycle 4 (Spring 1981)	Cycle 5 (Fall 1981)
Interstates	7.2	5.1	1.6	1.5	2.1
Principal arterials	24.2	21.0	5.7	3.6	4.8
Minor arterials	42.8	38.2	12.9	7.8	9.1
Collectors	38.9	45.0	16.0	9.0	12.9
Local roads	39.4	47.7	16.7	12.7	16.6

The trained-observer data have shown similar trends with respect to other surface, shoulders, and drainage conditions--sometimes confirming improvements and sometimes raising questions concerning the lack of positive results. In addition to this macro-level monitoring function, this condition survey is used to assist in allocating resources among counties and to check on the appropriateness of upcoming maintenance programs in the counties. Furthermore, it is slated to play a critical role in selecting candidate roads for major maintenance as opposed to continued routine maintenance in an integrated roadway management system currently being developed.

EFFECTIVENESS MEASURES

Critical to the performance monitoring concept is the ability to demonstrate the highway program's impact on users. Impact measures are usually the most difficult to interpret, since they are often heavily influenced by other than program variables, and the precise nature of these linkages is generally not well known. Factors that relate to the transportation goals of fast, safe, and efficient service are essential in measuring the impact of any transportation service, and in the highway area these translate into measures of user costs, accident statistics, and level of service. Table 2 identifies those measures that might be used to quantify changes in these three categories along with the possible sources of the data. Measuring the costs of transportation services to users is plagued by the difficulty in determining which portion of total vehicle operating costs to ascribe to highway condition. A partial solution is to include in a user survey a question about damage resulting from road conditions, but responses to this question will, of course, be limited to motorist's general perceptions. Another source might be information from vehicle inspection records, but such data would reflect the cost of all maintenance work done at the time of inspection, including that stemming from normal wear. It would not include work completed prior to inspection or at any time after inspection.

The measures relating accident statistics to the highway program are the most readily available within the Department. PennDOT maintains a computer-filed data base that is updated at least annually. Year-to-year change in the total number of accidents per 10 000 vehicle miles driven provides an approximation of the success of the safety aspects of the highway program. This analysis can be made more detailed by observing the change in yearly

Table 2. Effectiveness measures.

Factor	Measure	Source
Cost to users		
Vehicle maintenance	Average cost per respondent of vehicle repairs caused by road conditions	Citizen survey
Vehicle repairs	Percentage of vehicles requiring alignment or suspension repair	Vehicle inspection records
Accidents		
Number	Total number of accidents by type, extent of damage and contributing factors; accidents per 10 000 vehicle miles	State police reports and Bureau of Accident Analysis
At potentially hazardous locations	Change in number of accidents at potentially hazardous locations after project completion (standardized by ADT)	Safety improvement program
Level of service		
Point-to-point travel time	Change in time spent commuting from residences to work	Citizen survey
Average speed	Average speed in miles per hour or percentage of vehicles traveling below 40 mph	Sample observations
Volume/capacity ratio	Ratio of estimated 30th-hour peak traffic to design capacity	48-h traffic volume HPMS counts
Traffic congestion	Percentage of people responding that traffic congestion causes difficulties in getting to work or other places	Citizen survey
Perceived road conditions	Percentage of people indicating that road conditions have improved over the past year	Citizen survey
Pothole encounters	Number of times that vehicles encounter potholes in one day	Trained observer survey
Rideability	Percentage of roads with present serviceability index below terminal serviceability	Mays meter

accident totals, broken down either by type of accident (fatal, injury, or property damage) or by contributing factor (road condition, vehicle failures, etc.). The direct effect of the Department's activities on the number of accidents can be measured by the change in the number of accidents at potentially hazardous locations where corrective action has been undertaken.

Measures of level of service should indicate whether travel times, comfort, and convenience are increasing or decreasing. One alternative for estimating point-to-point travel times would be to select several routes in urbanized areas as representative segments and to observe changes in commuting time through the use of time and distance surveys. Given the difficulty in collecting these data, however, along with the questionable sensitivity of the measure, a more feasible approach might be to calculate the average time spent in transit between work and residence, based on responses to a survey of a random sample of highway users.

Average speed, a corollary indicator of level of service, could be calculated from speed data on a random sample of road segments similar to, or the same as, the sample used in the trained-observer survey. As an alternative, volume-capacity ratios could be used as a surrogate measure of average speed for the same random sample of road segments. Although changes in the volume/capacity (v/c) ratio are considered to be only a fair estimate of changes in average speed (7), estimating the number and percentage of state road miles by class of road, with peak period v/c ratios greater than 0.75, 1.0, and 1.25, for example, may be a relatively inexpensive substitute for direct travel speed indicators (8). Another indicator of effective service to the motorist is the "pothole encounter"--the number of times that vehicles encounter potholes in a day--that is computed by multiplying mean pothole counts for each MFC by their respective average daily travel.

In addition to point-to-point travel time, statewide citizen surveys can also be used to obtain information from the users' point of view regarding both user costs and perceptions of speed and traffic conditions on the highways they travel. Based in part on surveys conducted in North Carolina and Wisconsin, a citizen survey has been developed and tested for use by PennDOT. The items pertain both to road condition and effectiveness, and in general these perceptual indicators complement the hard data factual measures obtained from other sources. A mail-out version of this survey, which collected 3700 usable responses, was piloted in late fall of 1981.

PERFORMANCE MONITORING SYSTEM

The notion of a performance monitoring system connotes integration in the processing and use of the wide variety of indicators discussed in this paper. The objective of this research was to identify, develop, and select a set of performance indicators rather than to come up with a grand design for a monitoring system. However, since the development of particular indicators is keyed to specific management objectives and interests, they have not been developed in an operational vacuum but rather a sense of likely reporting frequencies and channels as well as potential use. Although a system design has not been the objective in terms of a single computerized management information system, elements are falling into place and an overall monitoring system is evolving as existing reporting procedures around the Department are modified and new data-collection efforts implemented.

The key to the development of a performance monitoring system as opposed to an array of data is the action component mentioned earlier in this paper; beyond data collection and processing, the information must be used for the effort to be worthwhile. The indicators discussed in this paper lend themselves to analysis of trends across time, and most also facilitate comparisons among organizational units. This kind of analysis serves to identify aggregate drops in performance and flag uneven performance across districts and counties. The results then must be reported to the appropriate managerial levels and relevant organization units on a timely basis, so that they can evaluate activities and take action accordingly. The action component does not refer to the corrective action itself, but to making useful information available to those in a position to take action when necessary.

REFERENCES

1. Monitoring the Effectiveness of State Transportation Services. The Urban Institute, Washington, DC, July 1977, pp. 3-6.
2. New Directions for PennDOT: A Fiscal Task Force Review. Pennsylvania Department of Transportation, Harrisburg, April 1976, p. 16.
3. S. Altman. Performance Monitoring Systems for Public Managers. Public Administration Review, Vol. 39, No. 1, 1979, p. 32.
4. T.H. Poister. Performance Monitoring: State Transportation Programs. Lexington Books, Lexington, MA, 1982 (forthcoming).
5. E.L. Miller. A Method of Measuring the Quality of Highway Maintenance. TRB, Transportation Research Record 506, 1976, pp. 1-14.
6. T.H. Poister and W.R. Moyer. The Pennsylvania DOT Trained Observer Survey: Design and Preliminary Results. TRB, Transportation Research Record 781, 1980, pp. 45-56.
7. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
8. Monitoring the Effectiveness of State Transportation Services. Urban Institute, Washington, DC, July 1977, pp. 36-37.

Abridgment

Program Development and Management: Pennsylvania's Integrated, Organizational Approach

LEE H. BOWSER, HARVEY HAACK, AND THOMAS D. LARSON

In an era of severely limited resources, top-level management must be intimately involved in the programming process. To be effective, in a management sense, the programming, budgeting, and authorization process must be closely integrated. This becomes even more critical as the nation shifts from new highway construction to transportation system management. In a sweeping organizational restructuring, the Pennsylvania Department of Transportation shifted from its traditional allocation approach of transportation programming to an integrated, organizational approach. This restructuring was accompanied by a parallel realignment of fiscal and system management functions. Program priorities as well as key programmatic decisions are now made through the Program Management Committee chaired by the Secretary and comprised of the Department's nine top managers. Programs are developed by the newly created Center for Program Development and Management, which develops and presents options to the Program Management Committee. Fiscal implications are analyzed by the Center for Fiscal and Systems Management. The entire process is monitored and managed through computerized management information systems.

To be effective in today's rapidly changing and highly uncertain world, top management needs to control resources and to make basic decisions concerning program direction. Otherwise, management cannot have confidence in its ability to deliver agreed-on projects.

The traditional allocation approach to transportation programming fails to sufficiently link financial planning and management with program development and management. In a sweeping organizational restructuring, the Pennsylvania Department of Transportation shifted from its traditional allocation approach of transportation programming to an integrated, organizational approach. This restructuring was accompanied by a parallel realignment of fiscal and systems management functions. Program priorities as well as key programmatic decisions are now made through the Program Management Committee (PMC) chaired by the Secretary and comprised of the Department's nine top managers. Programs are developed by the newly created Program Development and Management Center, which develops and presents options to the PMC. Fiscal implications are analyzed by the Fiscal and Systems Management Center. The entire process is monitored and managed through computerized management information systems.

TRADITIONAL ALLOCATION APPROACH TO PROGRAMMING

Pennsylvania's traditional approach to transportation programming was based on a county-by-county allocation of anticipated resources. These county-by-county allocations drove the capital program development process. Non-capital program development was scattered among various organizational units within the Department. Other than the 12-year forecast of available federal aid, there was almost a complete lack of financial planning.

Capital Program Development

Development of the Department's capital improvement program was coordinated through the former Bureau of Economic Research and Programming (BERP). Even though capital program development was coordinated through BERP, decisions regarding priorities were, in general, external to the Department. The prevailing process was driven by a highly structured county-by-county allocation process adopted by the Pennsylvania Transportation Commission.

Anticipated financial resources were allocated to the 67 counties according to the Commission's allocation formula. Within the 12-year county allocations, the Department's engineering districts and county planning agencies assigned preferred priorities to individual projects. Prioritized projects were then selected for inclusion in the recommended program beginning with the highest priority and continuing until the respective county allocations were exhausted. The recommended program was subsequently presented to the Pennsylvania Transportation Commission, which ordinarily adopted the program as its own.

As long as resources were plentiful (or, at least seemingly so as with bond financing), this cooperative process ensured local input. However, inflation continued to take its toll and current resources increasingly were dedicated either to maintenance of the existing system or to debt service on previously issued bonds. When the Commonwealth's ability to sell bonds expired, the process collapsed and a moratorium was imposed on all new construction work.

Non-Capital Program Development

Non-capital programming was fragmented among various organizational units within the Department. Categorical programs initiated during the 1960s and 1970s (such as safety and highway restoration programs) were assigned to functional organization units. The nature of the organization was to institutionalize these assignments. Constituencies developed, leading to a very parochial process even within the Department. This led to a variety of disjointed, narrow programs at the expense of the overall program structure. Inconsistent program structures tended to remain that way, in part, because the fragmented assignment of programming responsibilities either obscured or obstructed required changes.

Fragmented non-capital programs were less visible because of the relatively small dollar amounts involved with each when compared with the highly visible capital improvement program. These less visible programs, while significant in cumulative expenditures and impacts, were completely overshadowed by the capital program. As the capital program became impossible to finance, it appeared that the Department was doing nothing even though it still collected more than a billion dollars from Pennsylvania taxpayers each year.

Because of the fragmented approach to programming, information available to management was often inconsistent and not readily comparable between programs. Decisionmaking trade-offs required by ever-increasingly scarce resources simply could not be made. This denied top management the opportunity to assess competing requirements in any meaningful way.

Financial Planning

The failure to integrate decision-making into the programming process contributed to the misunderstanding and confusion that existed both within and outside the Department. Further adding to the confusion was the lack of top-management involvement in linking the budget process with programming.

In the early 1970s, inflation notwithstanding, the Department had continued an ambitious program of highway construction financed largely through bond sales. Bond sales had averaged $250 million a year, reaching a high of $440 million in 1976. By 1978, Pennsylvania's highway debt had increased to its current level of $2.3 billion--twice as large as any other state in the nation. Bonds will not be fully retired until the year 2005, and debt service through 1990 will exceed $190 million per year.

By 1977, the lack of integrated financial planning and program development led to a moratorium on construction. The state had exhausted its capacity to borrow money for highway construction and could no longer match federal aid. Literally dozens of modern, multilane, divided highways had been started all over Pennsylvania and were left partially completed--leading to nowhere, connecting to nothing.

The near absence of financial planning during this period had several programmatic effects. The financial constraints estimated for program development focused on total funds available during the 12-year period. Within the overall 12-year financial constraint, projects proceeded to implementation on a first-come, first-served basis. Shorter-term program-related financial issues were not addressed in any systematic fashion.

Understanding transportation programming under the fragmented, allocation approach helps to explain the mentality that continued with big-ticket construction (using bond financing), while the existing highway and bridge system crumbled from age, weather, and overuse; that continued to rip up basically good roadways in the name of safety and/or operational improvements while adjacent roadways lay riddled with potholes, but unattended; and that continued to finance improvements with 100 percent state funds (bond financed) when, in fact, these same funds could have been highly leveraged against federal aid that lapsed and was reallocated to other states.

INTEGRATED ORGANIZATIONAL APPROACH TO PROGRAMMING

The new administration responded to unrealistic, fragmented programs and fiscal chaos by taking an integrated, organizational approach to programming. The first step was to develop a clear set of priorities as a framework for program development. Then, beginning with the legal framework established by Pennsylvania's constitution and statutes as well as applicable federal laws, the products of the programming process were defined. At the same time an organizational framework was established to ensure top-management control over program and fiscal matters.

Priority Framework

The priority framework for program development shifted emphasis from new construction to restoration of the existing transportation system. While this policy pervaded the state's entire transportation program, the initial efforts were focused on restructuring the highway program. The Secretary established four groups of work activities. The first priority was given to routine maintenance, including general maintenance, maintenance and upgrading of equipment, traffic services, winter maintenance, and roadside services. Second priority was given to improvements to the existing system. This group of projects included restoration improvements on roads and bridges, bridge replacements and rehabilitations, and operational improvements. The third priority was given to the highly leveraged federal-aid completion programs, including Interstate highway completions providing nine federal dollars for one state dollar, and the Appalachian development highway program providing four federal dollars for one state dollar. The last priority was given to other federal-aid completions in the less leveraged primary, secondary, and urban systems programs. These programs only bring three federal dollars for each state (or local) dollar. Figure 1 shows how priorities were reflected in the state's restructured highway program.

Organizational Framework

The PMC was established to take advantage of the collective background and experience of top management within the Department. Committee members include the Secretary of Transportation as chairman, the Department's five Deputy Secretaries (for Planning, Administration, Highway Administration, Safety Administration, and Local and Area Transportation), and the new Directors of Fiscal and Systems Management, Program Development and Management, and Communications.

Fiscal management and computerized information systems were pulled together into a Fiscal and System Management Center. Budget priorities and the budget structure were revised to enable immediate production of a transportation product with very limited resources. The Department's past bond-financing approach was changed to cash financing. Cash-flow management techniques were instituted, and, for the first time cash flows were projected for two years in advance. Management information systems were also rationalized and instituted throughout the Department.

Program development and management were consolidated into a Center for Program Development and Management. Consolidation was accomplished more by transferring responsibilities previously residing in the operating divisions of the Department than by transferring individuals involved. It was determined that to transfer individuals would be too disruptive. Restructuring led to three divisions within the program center: (a) project assessment, (b) program development, and (c) program management. Figure 2 shows the general organization of the program center.

The Office of Press Secretary and Director of Communications was also established to coordinate all liaison with the media as well as with the members of the Pennsylvania General Assembly.

Procedural Framework

The program development process in Pennsylvania now consists of five distinct steps with respect to individual projects: (a) initiate, (b) review and prioritize, (c) select, (d) schedule, and (e) fiscal release. The five steps are assigned in stages and by organizational unit for highway program development. Program development other than highways--public transportation, airport development, and rail--is in various phases of development. The identification of stages and organizational assignments has defined responsibilities and decision-making points to overcome the previous confusion and misunderstanding.

Within the organizational framework, the Fiscal and Systems Management Center prepares multiyear accrual and cash-flow projections showing estimated state financial resources available for transportation programs. Estimates developed around high and low scenarios are provided to the Program Development and Management Center. The Fiscal and Systems Management Center also reviews and releases projects, phases of projects, or programs prior to initial authorization by the PMC and, again, prior to construction letting.

Figure 1. Priority program groups.

Group A – Routine maintenance (including general maintenance, maintenance and upgrading of equipment, traffic services, winter maintenance and roadside services).

Group B – Improvements to the Existing Highway System

- Restoration Improvement on Roads
    - Interstate Restoration
    - Non-Interstate Federal-aid roads
    - Off Federal-aid System roads
- Restoration Improvement of Bridges
    - Federal-aid System Bridges
    - Non-Federal-aid System Bridges
- Bridge replacements and rehabilitation
    - Federal-aid System Bridges (State and Local)
    - Non-Federal-aid System Bridges
- Operational and Safety Improvements
    - New Initiatives to Save Lives and Reduce Congestion
    - Transportation Systems Management Improvements

Group C – Interstate and Appalachian System Completions

Group D – Other Federal-aid Completions

The Center for Program Development and Management maintains distinct project assessment, program development, and program management capabilities. For the first time, an assessment of competing requirements and alternatives is taking place in a systematic fashion providing the foundation on which program options can be developed. More importantly, the information is readily available to top management. The program center prepares and maintains multiyear federal-aid forecasts, within which program development is constrained and options for leveraging available state funds are developed. All program-project authorizations are now released through the program center. By and large, this authorization release is accomplished via a computerized project management system--another new initiative by the Department.

Following certification by the program center, fiscal release by the fiscal center, and action by the PMC, transportation programs, projects, or phases of projects are released for implementation. Within these authorizations, any departure from established program schedules is immediately brought to the attention of the program center. Also, any departure from the approved scope of work or from the approved cost estimates by more than 15 percent or $500 000, whichever is smaller, must be justified in writing to the PMC.

Revisions to the authorized program are reviewed on a case-by-case basis by the PMC at weekly meetings. Guidelines have been established by the PMC so that minor adjustments can now be authorized by the program center.

Products of Priority Programming Process

The primary products of the integrated, organiza-

Figure 2. Center for program development and management: organization.

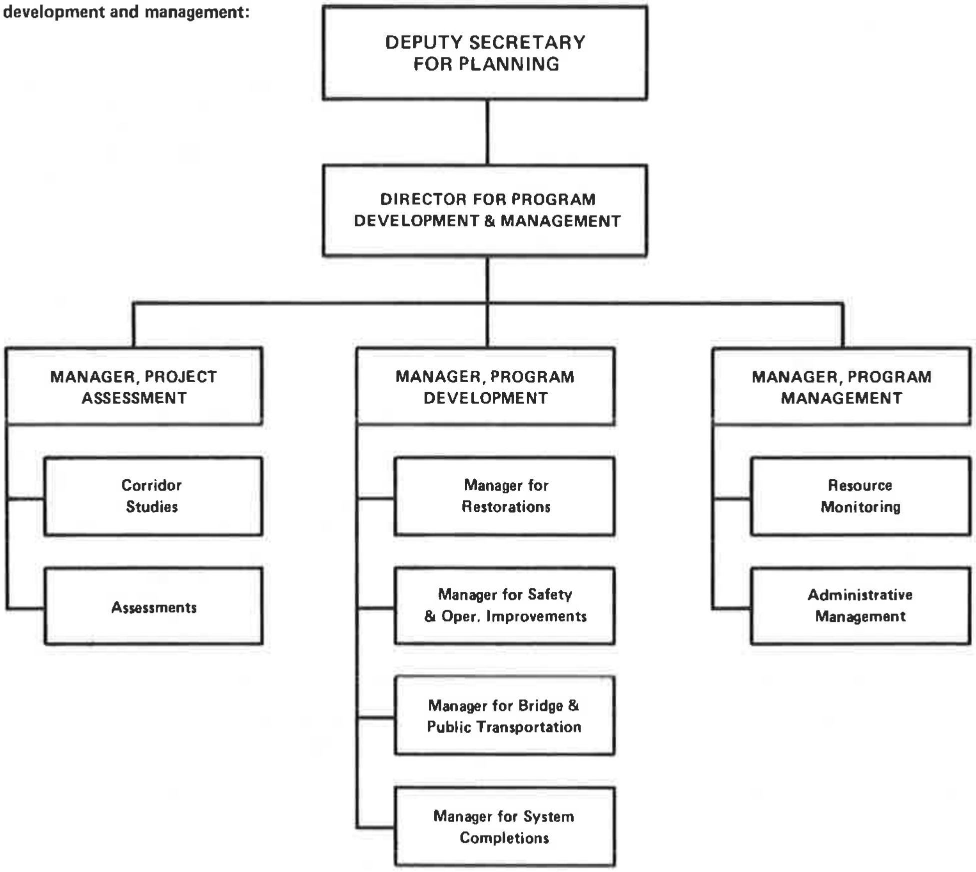
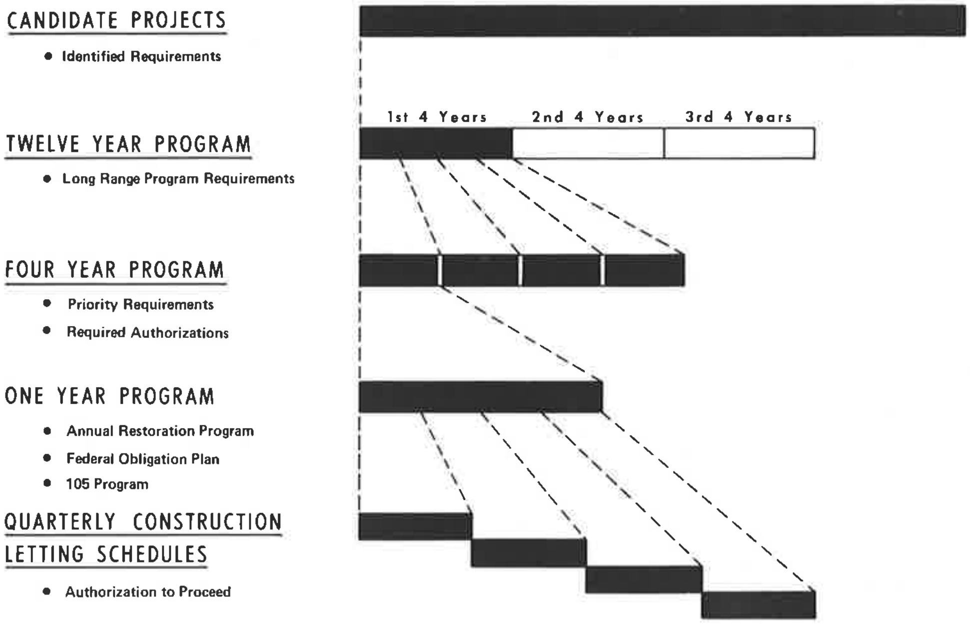


Figure 3. Program development.



tional approach to transportation programming are 12-, 4-, and 1-year programs, Figure 3 shows the relation between the primary products of the integrated, organizational approach to transportation programming.

For the 12-year period, there is a 12-year transportation program as required by state law. The 12-year program is reviewed, revised, adjusted, and extended every 2 years to cover, in general, capital improvement projects. The review and revision effort is undertaken in cooperation with county and regional officials. Recommendations are focused through the Program Development and Management Center, which initiates program development guidelines and criteria. The Program Development and Management Center develops alternate scenarios for the 12-year period based on assumed, alternate levels of federal and state funding. Within these scenarios, options are then developed first for consideration by the PMC and ultimately by the State Transportation Commission.

For the four-year period, there is a list of project phases (by priority grouping) expected to be initiated and/or completed within four years. The four-year priority program enables the Department to concentrate its resources--financial, human, and physical--on meeting specific objectives. The four-year priority program details the list of project phases on which Department managers are authorized to work. Compliance with these specific authorizations is ensured through the interfacing of the computerized project management system and the Department's computerized accounting system. Both the fiscal center and the program center monitor authorizations for compliance.

For the one-year period, there is now a list of project phases by priority grouping that are expected to be active during the year. The list includes the schedule of lettings for specific projects moving to construction during the period. It is also a reflection of the Department's planned federal-aid obligations for the year. Within the year, a detailed reconciliation between project activities and the one-year program occurs. The detailed reconciliation covers cost escalation within estimated cash available and required changes in project scope, costs, or scheduling. The changes may be dictated as a result of either project development or decisions to deliberately downscope improvements to remain within limited financial resources. Detailed reconciliation of the one-year program permits development of a firm-letting schedule for public announcement at the beginning of each quarter.

SUMMARY AND CONCLUSION

In summary, the key to successful program development in Pennsylvania has been the Department's ability to bring together programming and budget functions at the very top level of management. Information and monitoring systems have been instituted that allow top management not only to be involved in decisionmaking but also to monitor implementation. This is accomplished by active involvement of metropolitan and county planning organizations in the program development process and continuous liaison with the General Assembly. Pennsylvania has developed both a sensitive and effective program. The Department's integrated, organizational approach to programming has enabled Pennsylvania to more than double the amount of federal aid obligated within 20 months. In fact, over the past two years, Pennsylvania has obligated more federal aid than any other state in the nation.

Finally, open and effective programming has been one of the key contributing factors to rebuilding the Department's credibility with the General Assembly. Three years ago a disenchanted General Assembly considered legislation to dissolve the Department of Transportation. Last session, with an overwhelming, bipartisan vote of confidence, the General Assembly enacted a 3.5 percent oil franchise tax to stabilize the Department's declining motor fuel tax revenues. For the first time in a decade, the General Assembly understands and endorses the Department's program, believes that it will actually be accomplished, and because of this, has provided the revenues to finance it--a major accomplishment.

Abridgment

ECONS: Case Study in Program Development Through an Integrated, Organizational Approach

HARVEY HAACK, THOMAS BRYER, AND ROY TAYLOR

This paper describes how the new management philosophy in the Pennsylvania Department of Transportation has been linked with existing technical expertise within the Department to create a major new program aimed specifically at saving lives and reducing congestion. Despite an inauspicious beginning, the ECONS program is now finally understood and embraced by local officials. With local officials more involved in project selection and evaluation, differences of opinion that previously led to the best projects (from a technical perspective) being rejected are now resolved jointly by the Department and local officials. Although the result is a more modest program than originally conceived, the long run will no doubt demonstrate an overall greater cost effectiveness in conserving energy, reducing congestion, and improving safety. As efforts to restore existing highways and bridges take hold and the Interstate and Appalachian construction programs wind down, it may well be that this evolving program to conserve energy, reduce congestion, and improve safety becomes the state's highway program of the future.

In the early 1970s, Pennsylvania had one of the most ambitious highway construction programs in the country. Toward the mid-1970s, things started to fall apart. While literally billions of dollars in bond money were being spent for 100 percent state financing of expressway-type highways, the federal-aid program was being ignored. By 1978, Pennsylvania had fallen approximately three years behind in its use of federal aid and had accrued the largest unobligated balance in the country--more than $800 million. By 1979, in addition to the enormous unobligated balance, almost half a billion dollars had been reallocated to other states.

An expressed goal of the new management was to avoid additional loss of federal aid. A first step was to analyze the extent that limited state dollars could be leveraged with federal aid. During this exercise it was discovered that Pennsylvania had access to nearly $200 million in federal aid that required no state matching funds at all. This was through the so-called Federal-Aid "G" Fund established through the 1973 Federal-Aid Highway Act and broadened in the 1978 Act. This legislation provides that up to 10 percent of all Interstate, primary, secondary, and urban apportionments may be used for 100 percent federal financing for projects to eliminate the hazards of railway-highway crossings and to install traffic control signalization.

A NEW INITIATIVE

A new initiative to save lives and reduce congestion evolved from the discovery that $200 million was available to Pennsylvania for 100 percent federal financing of certain projects. Another $75 million in regular federal aid was added to create an overall $300 million program.

The objective in developing the new initiative was quite simple. Given the lowest-cost but most effective ways feasible, identify the 30 most hazardous railway-highway crossings in the state, the 350 most critical intersections, and the 50 most congested urban corridors. The overall goal was to develop and implement a program that would, by 1985, save 300 lives and 4 million hours of both personal and equipment time.

Although the objectives of the new initiative were quite straightforward, program development and implementation proved to be an elusive exercise. Not the least of the hurdles was the name of the program. The New Initiative Program to Save Lives and Reduce Congestion eventually became ECONS--an acronym for ENERGY CONSERVATION, CONGESTION REDUCTION, AND SAFETY IMPROVEMENT.

Other hurdles also had to be overcome. Perhaps the greatest was the notion that $300 million in new federal funds had been found that required no matching funds. What the Department had great difficulty in articulating was that the $300 million was not new money. Rather it was hoped by the Department that state and local governments working together could creatively innovate a new program to actually save lives and reduce congestion. Because of the poor fiscal situation, it was imperative that the program require a minimum of nonfederal matching funds. By taking full advantage of so-called federal-aid "G" funding, a program requiring only $25 million in non-federal matching funds was possible. Such a program could leverage each state-local dollar more than nine times. At a time when Pennsylvania was turning back half a billion dollars in federal aid for lack of state matching dollars this was an exciting proposition.

Another very difficult hurdle resulted from the way the new initiative cut across the traditional federal-aid Interstate, primary, secondary and urban system programs. Funding for the new initiative had to come from these categories. Local planning agencies felt as though these funds had already been earmarked for projects that, in their minds, had a very high priority. The fact that the state could not match federal aid and was otherwise incapable of carrying out "their" priority programs fell (at first) on deaf ears.

Another hurdle came soon after the first round of technical evaluations was completed. The Carter Administration, in an anti-inflation move, placed ceilings on how much federal aid each state could obligate. In effect, the $800 million balance of unobligated federal aid that had accrued to Pennsylvania was inaccessible. Some $200 million, which could have been used for 100 percent federal funding of projects to save lives and reduce congestion, now had to compete with closed bridges and Interstate completion deadlines for priority use of federal aid.

Project Selection

The Department's goal to have $300 million worth of ECONS projects implemented within four years led to an extremely tight timetable for project submission. The first step was to develop candidate projects. All county planning commissions, metropolitan planning organizations, and highway engineering districts, as well as the larger municipalities, were asked to submit candidate projects.

A list of 1061 candidate projects was developed. Preliminary estimates totaled $580 million--almost twice the $300 million program target. In addition, projects on the federal-aid primary system exceeded target values by a factor of three. This was an insurmountable problem since primary funds available to Pennsylvania were already four times oversubscribed.

Technical Evaluation

Concurrently with developing candidate projects, the Department hired a consultant to develop a methodology for evaluating projects. Factors to be considered were benefit/cost ratios, number of deaths and injuries reduced, amount of delay reduced, fuel saved, and qualitative factors such as economic growth. The basic aim was to establish a group of common measures of effectiveness. The measures of effectiveness established were delay, fuel consumption, and injury and fatal accident occurrences. Four categories of problems were identified: (a) spot locations with high accident experience, (b) congestion problems at isolated intersections, (c) congestion problems along urban arterials, and (d) congestion problems within urban grids. Delay, fuel consumption, and accident impacts could be identified and measured for each candidate project within these categories.

Limited manpower with expertise in traffic safety and operational improvements led the Department to hire four consultants to analyze and evaluate candidate projects. Because each consultant was responsible for a certain geographic area of the state, it was extremely important that the values of delay, fuel consumption, and accident reduction could be comparatively applied.

High Accident Locations

Analysis of high-accident locations was based on the state's Location Priority Report. High-accident locations were analyzed through collision diagrams, accident patterns, and substandard design features. Improvements to upgrade substandard design features were then determined and estimates made of the savings that could be achieved.

Congested Intersections

Information required for intersection analysis included turning volumes during the peak hour, average daily traffic, physical characteristics, and existing signal timing and phasing. The existing condition was then optimized by using Webster's method of determining effective green time and cycle length (1). Saturation flow rates needed for computing cycle lengths and effective green times were initially determined by using intersection capacity charts with demand volumes. Delays during the peak hour were then computed for each approach lane based on computed effective green times and actual saturation flow rates with delay being a function of degree of saturation for unsaturated intersections and the size for queues of oversaturated intersections. The next step was to determine how to reduce intersection delay. The Highway Capacity Manual provided the basis for determining critical approaches and turning movements (2).

Once a hypothetical package of improvements was identified, the "improved" condition was analyzed to determine delay. Delay values were then compared with delay values for the "optimized" existing intersection to determine how effective improvements would be.

Next, off-peak delays were analyzed. The average off-peak hour was determined by summing the approach volumes occurring from 6:00 a.m. to 12 midnight, deducting the peak-hour volumes, and then dividing by the number of off-peak hours. The same procedures described for the peak-hour analysis were then followed to determine delay savings during the off peak. It was found that the delay savings during the accumulated off-peak hours varied between 90 and 140 percent of the peak-hour delay savings.

Fuel consumption saving was based solely on delay. It was determined by taking the product of the delay saving and average vehicle fuel consumption at idling rates (0.63 gal/h).

Accident analysis procedures for congested intersections depended on whether the intersection appeared in the state's Location-Priority Report. For those intersections listed in the report, analysis was the same as for high-accident locations described previously. If an intersection did not appear in the report, appropriate accident reduction factors were applied to proposed improvements based on the site's accident history.

Congested Arterial Corridors

By using speed and delay runs, critical intersections were identified. Each intersection was then analyzed by using the same methodology as for isolated congested intersections. If the geometry of the roadway and the spacing of signals were favorable for interconnection, each signal was retimed by using the optimum cycle length of the critical signal(s). The delay difference of offset computer program was then used to determine arterial delay during the peak hour with interconnected signals (3). Arterial approaches to the main arterial were assumed to operate at level-of-service D or better. The values derived from the delay difference of off-set program were then compared with the approach delays for optimized but nonconnected signals to determine the net savings from interconnection during the peak hour. By using the same concept as the average off-peak hour in the congested intersection discussion, the average and total off-peak savings due to interconnection were determined.

Congested Urban Grids

Conceptually, grid-system analysis was an extension of urban arterial analysis. Speed and delay runs were performed during peak and average off-peak hours. Critical intersections were identified and each intersection analyzed as described previously. Delay savings were based on various signal system improvements. The total stopped delays were summed for all links, then percentages were applied for various types of improvements to determine annual savings for each type of improvement.

Comparative Analysis

For comparative analysis, benefits from potential improvements were expressed in terms of number of vehicle hours, gallons of gasoline, property damage, and injury and fatal accidents that could be saved each year. Values were then converted to dollars and compared with project costs.

Lessons Learned

As would be expected in developing any new program, a number of problems emerged. In retrospect, a lot of time and effort was wasted because of inadequate prescreening of projects. Another problem occurred when it was discovered that the four consultants were not consistent in their application of procedures for project analysis and evaluation.

Initial Results

Of the 1061 candidate projects generated initially, 109 projects survived the first-round technical evaluation. These projects were then further evaluated to ensure they met the basic goals and objectives of the ECONS program. Finally, projects

Table 1. Federal-aid categorical splits.

		Federal Funds ($000 000s)				
Item	Total	FAP	FAS	FAU	Total	Matching Funds
Initial targets	300.0	85.5	22.5	162.0	270.0	30.0
First round	7.7	4.4	0.2	1.6	6.2	1.5
Second effort	24.7	10.3	0.0	10.1	20.4	4.3

Table 2. Estimated annual benefits.

Item	Lives Saved	Hours Saved	Fuel Saved (gal)
Initial targets	300.0	4 000 000	-
First round	2.2	1 162 100	750 000
Second effort	4.5	1 427 300	900 000

were prioritized on a statewide basis. Of the 109 projects submitted, 50 projects clearly did not meet the goals and objectives of the program and were dropped from further consideration.

The first-round submission had a cutoff benefit/cost criterion of 3.0. Some 28 projects met this criteria. Annual benefits totaled $5 754 000 compared with annual costs of $1 687 000 that yielded an overall benefit/cost ratio of 3.4. Collectively, the 28 projects annually would save 1.1 million h of stopped delay during the peak hour, 750 000 gal of gasoline, 53 serious injuries, and 2 lives. Estimated cost of the 28 projects was $7 669 000, but federal funds only made up 80 percent.

Management was disappointed in the first-round submission. First, a 90 percent federal participation rate had been set as an overall program objective. Second, the ECONS program requires a combination of primary, secondary, and urban system funding. Since Pennsylvania's anticipated primary apportionment was already four times oversubscribed, federal-aid primary funds required by the ECONS program had to be strictly limited. Finally, the 28 projects submitted for the first round were not nearly as effective in saving lives as originally hoped.

Management directed staff to review the original submission. The first-round resubmission consisted of 20 projects costing $3.3 million. While federal-aid primary funding required was reduced to $1.6 million, the federal participation rate remained at 80 percent and lives saved at 6 within 4 years. Nevertheless, because of the significant time and fuel savings, the 20 projects were authorized for construction.

A SECOND EFFORT

The disappointing results of the first round led to a reassessment of the entire program. Management decided that in spite of federal obligation ceilings, a modest ECONS program would be pursued.

For second-round projects both qualitative and quantitative factors were considered. Qualitative factors included (a) local priority, (b) local participation in funding, and (c) impact on the local economy. Quantitative factors included (a) the overall benefit/cost ratio, (b) the energy benefit/cost ratio, (c) the safety benefit/cost ratio, (d) fatal accidents saved, (e) average daily traffic, (f) share of federal funding, and (g) share of local funding.

Second-round projects had to meet the following criteria: (a) overall benefit/cost ratio-->3.0, (b) safety benefit/cost ratio-->2.0, (c) fatal accidents saved-->1 in three years, (d) average daily traffic-->15 000 vehicles, and (e) federal participation rate-->90 percent.

In all, 161 projects were submitted costing $43.8 million. This was narrowed to 70 projects totaling $24.7 million. Nevertheless, even with stricter criteria for federal participation rates and the use of federal-aid primary funds, the two problems still persisted. Table 1 shows the federal-aid categorical splits. In this case, management decided to authorize the 70 projects provided that metropolitan planning organizations endorse them. All 70 projects were subsequently endorsed. Table 2 provides an estimate of annual benefits.

AN ESTABLISHED PROGRAM

Now, after almost two years of starts, reassessments, and restarts, ECONS has become an established program. Energy conservation, which was considered more a byproduct of the new initiative to save lives and reduce congestion, has now become a basic element of the ECONS program.

While a great deal was learned from initial efforts to develop the program, the basic lesson learned was that the metropolitan planning organizations must be brought into the program from the very beginning. During negotiations with metropolitan planning organizations in developing their respective unified planning work programs, corridors were selected for ECONS examination. In all, 66 corridors were evaluated during FY 1981-1982.

SUMMARY AND CONCLUSIONS

Despite its inauspicious beginning, the ECONS program is now finally understood and embraced by local officials. With local officials more involved in project selection and evaluation, differences of opinion that previously led to the best projects (from a technical perspective) being rejected are now resolved jointly by the Department and local officials. While the result is a more modest program than originally conceived, the long run will no doubt demonstrate an overall greater cost effectiveness in conserving energy, reducing congestion, and improving safety.

In the lessons-learned category, it can be concluded that

1. Traditional safety programs do not lend themselves to programs that also include congestion reduction and energy conservation;
2. Narrow federal categories (primary, secondary, and urban systems) restrict a systems approach to intersection improvements that have a mix of federal-aid system designations;
3. The gauntlet of federal regulations and bureaucratic reviews inherent in federal-aid programs makes it difficult for low-cost operational/safety improvements to survive the process;
4. The state of the art does not lend itself to the development of a broad, statewide goal-directed program;
5. Overly rigorous analytical methods become unwieldy when applied by a variety of individuals to an array of improvement categories;
6. A great deal of cross-education is required to achieve agreement on what is "best" in the minds of technical evaluators and what is "best" in the minds of local officials; and
7. It takes both strong, articulate leadership and willing local cooperation to develop and carry

out a goal-oriented program that cuts across traditional funding sources.

Finally, worthwhile goals and objectives simply do not come easily. Nevertheless, despite the constraints of restrictive federal funding categories, overly narrow analytical procedures, general resistance to change, and the inability to articulate the potential benefits of doing things a little differently, reducing congestion and saving lives remain worthwhile goals. Now, after two years of cross-education, the state's transportation department is pleased to join with local officials in the continuing identification and selection of cost-effective projects that actually do conserve energy, reduce congestion, and save lives.

REFERENCES

1. F.V. Webster. Traffic Signal Settings. Road Research Laboratory, London, Tech. Paper No. 39, 1958.
2. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
3. Improved Criteria for Traffic Signal Systems in Urban Networks. NCHRP, Rept. 124, 1971.

California's Engineered Systems Approach to Project Delivery and Capital Resource Management

JAMES F. McMANUS

The California Department of Transportation's development of an engineered systems approach to project delivery and capital resource management is discussed. Effective management of productivity is the important key to the successful delivery of a transportation program. The California system focuses directly on the effective management of productivity through informed and timely decisionmaking in order to make things happen. This approach is used in resource management planning and then to measure the effectiveness of carrying out that plan.

Problems that face the professional transportation manager today are well documented. What was once a pure technical process now involves a multidisciplinary team approach to problem solving with a mixture of agendas and understandings of the real problems to be solved. Add to this an increasing number of uncontrollable external barriers, as well as inordinately long required process times, and it has become more and more difficult to forecast and maintain program delivery. The manager is confronted with constant change in program direction and composition due to a limited money supply or revenue base, while at the same time facing up to a basic responsibility to preserve an aging system and keep it operational. Continuing cost inflation spirals are resulting in rescoping and/or downscoping engineering designs to keep costs within allocation limits that result in a dichotomy of additional costs in time and effort thrust on an already limited staff. The number of smaller-sized, manpower-intensive projects is increasing in logarithmic proportions in an attempt to stretch a diminishing constant-worth dollar.

It would seem that in the purview of today's professional transportation manager, the only certainty is continuing uncertainty and limits. It has been said that the 1980s will more than likely be an era of limits for transportation. Money, staff, and time are limited, but demands for meeting broadening transportation needs will be unlimited. These limits and demands to a transportation manager mean just one thing--increase productivity.

Additional complexities surfaced during the 1970s when there was a national change in cultural climate, a new energy awareness, and the awakening of the era of limits. Highway departments had been highballing the development of a national network of highways as "the transportation system" for about 20 years and suddenly became "transportation departments." New responsibilities and requirements surfaced along with new technologies aimed at interfacing multiple air, land, and water modes into an integrated system. The transition is beginning to move forward aggressively with the highway corridor still the dominant surface facility for moving goods and people. The highway corridor has been expanded to a transportation corridor and now may include exclusive lanes and even tracks for high-occupancy vehicles at one end of the spectrum to lanes for bicyclists at the other end, in addition to cars and trucks normally found in a highway corridor. To keep all of these responsibilities in focus and balance, the transportation manager has had to slice the total program into elements and components that have varying goals and objectives, thus adding further complexities to managing in the world of limits.

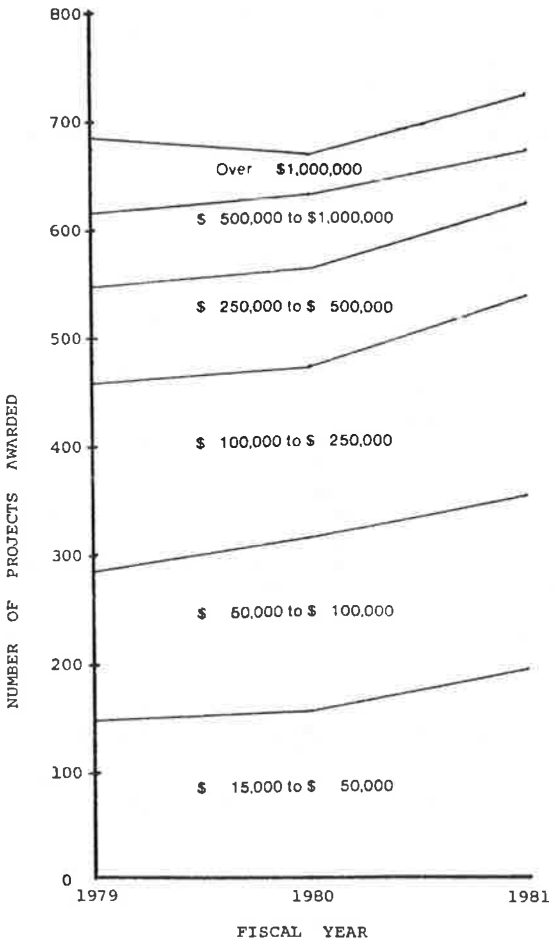
To bring order to all of the disorder, a manager obviously needs a resource utilization plan. In this type of environment, a systems approach to resource planning and decisionmaking becomes an important element in the successful management of productivity. Therefore, effective management of productivity is the important key to successful delivery of a transportation program.

A comprehensive and integrated information system can be used by the manager to establish a plan of program delivery to meet long- and/or short-term goals and objectives set for the program. The quality of information provided from this systems approach can affect the quality of the plan and ultimately affect productivity. The manager then can establish a mutual understanding and balance with staff between rates of productivity and the capability to accomplish the program. Placing this information into a systems context also enables all levels of management and staff to individually and/or collectively plan for rates of productivity to accomplish the established program goals. An essential element of the system then becomes maintaining information credibility in order to have a base for the exchange, communication, and measurement of accomplishments. As the inevitable change occurs and as long as all levels of management understand where they are at any point in time, the impacts of the change can be measured to minimize organizational trauma and establish a new goal for accomplishment.

Such a system must be comprehensive and yet relatively simple. The system must be responsive to management needs and be capable of providing information incrementally or collectively on the basis of the total transportation program, modal element, modal component, organizational function, project, or activity/task. The system must provide information for each part of the full management cycle: planning, programming, scheduling, staffing, budgeting, monitoring, evaluation, and a feedback loop to planning (see Figure 1). To handle effectively the myriad of demands for structured and timely information, manipulated in various formats, most often requires a system employing computerization.

Figure 1. Transportation program management cycle.

Figure 2. Number and size of capital projects awarded in California between June 1978 and July 1981.



Computerized management systems abound. Most are described as such incorrectly because many are basically administrative systems that allow people to watch things happen, usually after they have happened, while others forecast resources in pieces--people separate from time, time and people separate from dollars. Many are incomplete, leaving out important elements of a complete project. What has been needed is a comprehensive system with all resource needs tied together that points the way--a system that can respond to changing processes as they occur and can provide managers with complete, timely, and comprehensive information and options to enable them to make informed decisions that make things happen. Such a system has been developed in California and is the subject of this paper.

PRIOR MANAGEMENT SYSTEMS DEFICIENT

California, like many states, has had project-specific work plans loaded into its computerized data base for at least the past 12 years. The loading had to be done manually, project by project, utilizing data separately calculated from a large array of complex manpower management systems that became notoriously out-of-date with processes. Manually calculated supplements were then added. None of the management systems had direct interfacing with project schedules. Project schedules were manually cranked into the system by each project manager.

Usually, once a year, a gigantic manpower-intensive effort was launched statewide lasting from one to two months when all manpower resource needs were tied to project schedules. Under the decentralized management of that time, this effort was undertaken in 11 district offices and numerous headquarter units. Between redundancy on the one hand and omissions on the other, the whole exercise was suspect. Nonetheless, it became the base for the Governor's Budget. Manpower allocations were transmitted six months later and were pitifully out-of-date with everything. When all of this was loaded into the computer, we were able to produce beautiful management reports fraught with incredible information leading to total management frustration. Program scheduling was done independently by using this information and then management wondered why program delivery was so far out of synchronization with programming.

Overoptimism in project scheduling was rampant, and there was no backlog of completed projects to bring in to fill the breach when programmed projects were not deliverable. Obviously, capital programming was out of synchronization with delivery schedules at a time when project cost inflation was galloping out of control. With the deficiencies of the existing loosely controlled manpower systems, resultant organizational imbalances were not being identified in a timely manner and were also contributing to the problem.

As was the national trend, California was and still is being faced with an increasing number of low-cost, manpower-intensive projects. The trend during the past three years of contract awards shows that approximately 80 percent of the number awarded (about 575 per year) were less than $500 000 in size (see Figure 2). Conversely, the small slice of projects more than $1 million in size during this same period were approximately 85 percent of the total capital dollars awarded (not shown in Figure 2).

The deficiencies of the old procedures became apparent to top levels of departmental management and a proposal for an integrated systems approach to resource management was developed.

1978-1979--A NEW DIRECTION

During the 1978-1979 period, the California Director of Transportation launched a number of steps directed toward correcting resource management deficiencies:

1. Centralized all capital related resources management activities into headquarters with districts relegated to pure line responsibilities for implementation of centralized directions and decisions;
2. Redefined a role for the Deputy Director for Engineering to be responsible for statewide project preparation and delivery;
3. Approved formation of a central design unit in headquarters to supplement design units in the 11 districts (the central unit absorbs overflow work load resulting from any imbalances between program and staffing in the districts, and this unit also began work to develop a backlog of ready projects);
4. Commissioned a number of studies to find and recommend methods and/or opportunities to improve resources management in the department.

SYSTEMS APPROACH PROPOSED

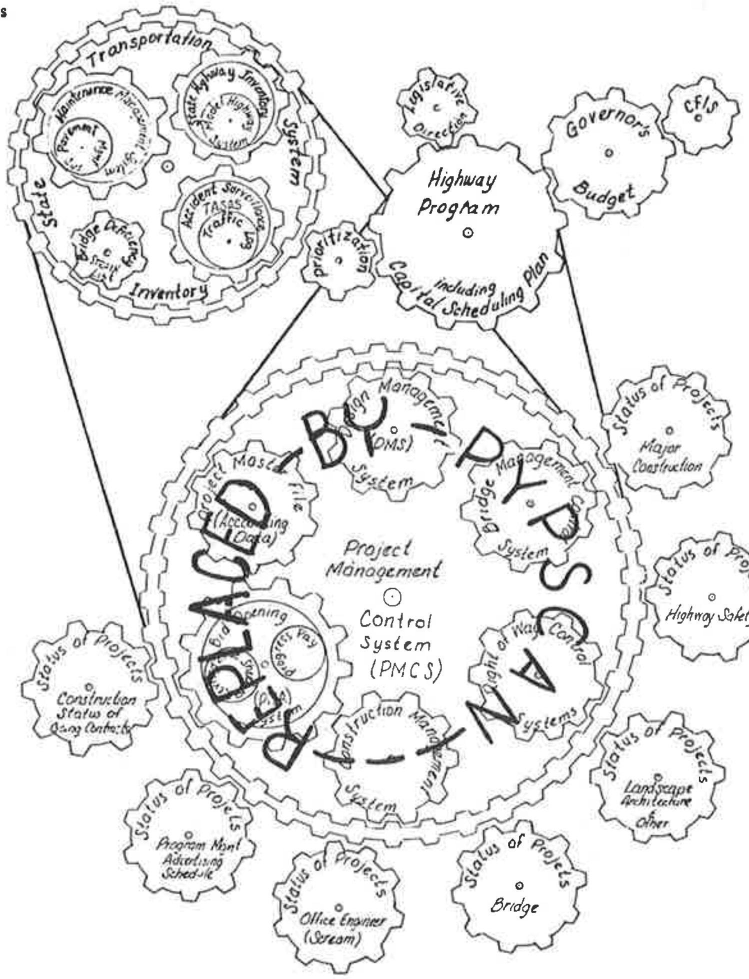
In April 1979, a special task force of district and headquarters technical experts and management staff was commissioned by the director to develop a centralized capital outlay and technical support budget process for the department. This process was to compliment the decision to centralize capital program management in headquarters with implementation of the capital decisions at the project level in the districts. Six weeks later, the task force presented a conceptual proposal to the directorate (Director and four Deputy Directors) for an automated capital scheduling plan (ACSP). The proposal, rather than limiting the focus to just a narrow budgeting process, envisioned development of a comprehensive, computerized, on-line management information system. The system would fully automate multiyear scheduling of all resources (money, time, and people) for the department's capital-related transportation program.

System output would include mutliyear assignments for about one-third of the department's 15 000-person work force. It would schedule all of the resources in an annual capital-related budget of $500-$600 million (including right-of-way and technical support), and provide project delivery scheduling that need only be limited to the extent desired by the department--5 years, 10 years, 20 years, forever. The initial plan would be based on the department's five-year program and would contain approximately 3000 projects. Finally, it would be dynamically responsive to change and provide current information on which to base resource management decisions. The task force specified that the design of the ACSP would

1. Be project specific. This concept expanded detailed resource management from an orientation that had been strictly highway to include all proposed transportation facilities undertaken by the department. The task force reasoned that a project required essentially the same elements for resource management purposes whether it be a traditional highway facility or a facility specifically for buses, intermodal transfer, rail, or aviation. The task force further reasoned that all capital projects went through the same basic development steps of planning, design, and construction regardless of whether the project was reconstruction, rehabilitation, operational improvement, or a total new facility and that transportation projects undertaken by the department require the same general types of resources to manage--namely, time, dollars, and people.
2. Be integrated into an existing project data base known as the Project Management Control System (PMCS). PMCS was designed 12 years earlier as the department's primary automated project data base system. PMCS, as originally designed, accommodates a multiple purpose system with capability to be linked through a series of computer program modules for calculating and reporting all elements of a complete management resource information system (Figure 3). PMCS has been used for a number of years for entering and reporting project-specific inventories of the entire transportation system in California, for calculating and reporting project priorities, for multiyear programming and annual budgeting of these same projects, and monthly project status reporting from inception through contract completion.
3. Retain the same basic project identification system. California uses a specific hierarchy of codes and numbering criteria for establishing uniqueness for each project or item in the department. This series is coded on every document and accounting file entry for any purpose in the department. As an example, each capital project is given a two-digit location identifier (specific district or headquarters unit), a six-digit unique project number, and a four-character alpha-numeric program code to identify the purpose of the project. This last code provides for additional file sorting by the various program categories managed by the department and for tabulating and monitoring of the annual purpose-oriented state program budget. This feature provides multisort capability to enable reporting and arraying management information in a variety of responses.
4. Include the design of a new computer module in PMCS that would automatically calculate schedules and manpower required for each project in the state transportation improvement program. The approach would be project-specific and, while complex and comprehensive, should be simple to maintain and update. Research into a number of systems designed by others indicated that the complexity of input and variety of detailed project file maintenance at the project-manager level creates large problems in terms of on-time data credibility. Conceptually, this system would not require very detailed task/activity reporting. The project manager, after initial loading of a minimal amount of basic project data needed to make the calculation, would only need to report actual progress in terms of actual dates of accomplishment or new target dates for designated milestones along the calculated project timeline. The new computer module would contain all of the standard formulas and variable factoring to adjust for any special complexities needed in the calculation on a multitude of project types. The system would then automatically calculate and/or update timeline scheduling and manpower distribution from inception of the project through the writing and submission of the final report after completion of construction. The system would be on-line with direct entry of data, calculation, and updating done through cathode ray tube-type terminals located in the districts and headquarters. Specific terminal identification, except for a few master terminals located in headquarters, limits access to specific files. Computer "locks" also protect file integrity.

It was decided by the task force that the myriad of finite detail was not absolutely essential for effective program monitoring and management, cash flow management, and project management and deliv-

Figure 3. California's computerized project-related data base has been in operation since 1969 with improvements ongoing ever since.



ery. Simple "exception style" management reporting was most effective for timely decisionmaking. Years of experience with our existing detailed manpower management systems verified that too much detail tended to create high "fog indices." It also reduced flexibility in project management and resulted in management focusing on the trees rather than on the forest. While a comprehensive system is needed to answer management inquiry, the amount of actual detail involvement in operating and maintaining any system does reach a cost-effective balance point, and data credibility is not directly proportional to the amount of detail involved. By nature and definition, management systems are a threat to the people being asked to maintain and update the system. Many people agree that data malnutrition will destroy a system faster than any other factor.

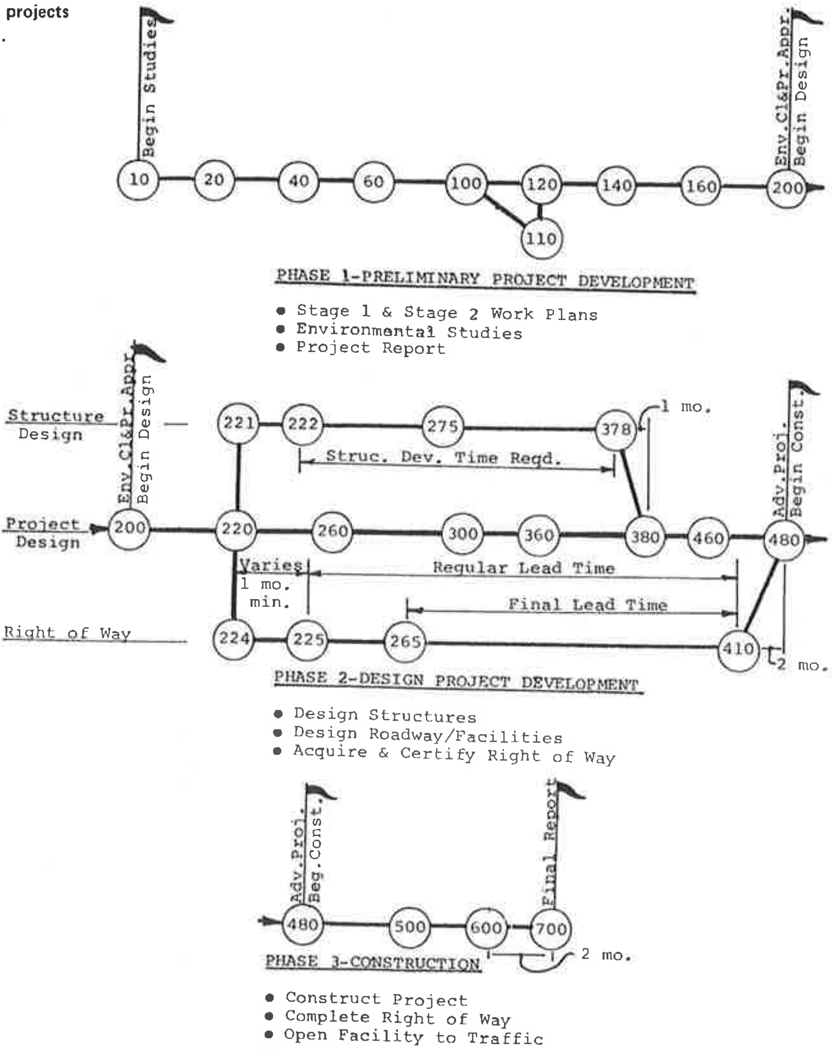
To encourage continuous user participation in the simplified amount of data maintenance required (besides keeping all levels ot management interested), the system was to be designed with positive, automated linking between all categories of manpower required and the project schedules. Therefore, if actual project schedules change, and the change is justified and approved, then manpower category levels required for all remaining steps automatically change. Obviously, to maintain optimum manpower levels, it becomes most desirable for the user and project manager to maintain the shortest project timelines--an important factor and ingredient to maintaining optimum productivity.

This new computer module system to Automate the Capital Scheduling Plan (ACSP) would be named Person-Year and Project Scheduling and Cost Analysis (PYPSCAN) and that the project to make it happen would be titled the ACSP/PYPSCAN Project.

5. Include a project team to be designated with a project manager and team members selected from within the department to design, computerize, and implement the new system. The multidisciplinary team proposed in this recommendation included engineers and right-of-way agents with expertise in the various technical project functions involved at both headquarters and districts, management and budget experts from headquarters, and the computer systems manager at headquarters that would be involved in the PMCS modifications. Most of these people were to be utilized on a part-time basis. A list of in-house consultants, mainly management, e.g., district directors and division managers in headquarters, were designated as a first-level review team for the ACSP/PYPSCAN Project with emphasis on the concept of the system output reporting. The directorate was designated as the approval authority for all major steps in the process.

6. Be developed as the ACSP/PYPSCAN Project and would be developed in three separate units. The first unit was the basic PYPSCAN development to calculate manpower needs and schedule all projects in the department's capital program. The timeline on the first unit was established at 12 months. The second and third units were for developing a full range of system and management reports and for investigation, design, and implementation of further detailing the basic PYPSCAN concept. The second and third unit schedules would extend the total life of

Figure 4. The milestone control plan for all projects in the new management information system.



the project up to 36 months.

In June 1979, the transportation director approved the task force proposal and recommendations for the ACSP/PYPSCAN Project. The project team was selected, organized, and within a few days of the approval, began conceptual design work on unit 1.

DEVELOPING THE SYSTEM

The project team's approach to handling the very short timeline established to design and implement unit 1 was to divide the work to be done into unit segments, with the first four months assigned to detail design the base system. The entire team worked together on step one, which was to reach a consensus on a standardized activity network and establish a standardized milestone track through the network that would typify most projects. The entire team then worked together to reach a consensus on the variables, modifiers, and complexity factors that would be used in the design of the system. The team was then divided into four separate assignments:

1. Develop policies, procedures, roles and responsibilities and obtain a management agreement and commitment;
2. Develop a design for calculating project schedules;
3. Develop a design for calculating project manpower; and
4. Develop a design for the computerization, including an outline, of input data requirements, on-line features and requirements, basic reports, and user instructions.

The first unit of this system was designed and computerized in about seven months, with data and computer formula calculation testing taking about another four months to complete. During May 1980, 11 months after starting, the project team implemented the basic manpower planning and project scheduling unit of the system statewide.

Policies, Procedures, Roles, and Responsibilities

One of the first and most essential steps in an undertaking such as this is agreement and commitment at the highest level and authority, especially when it is a system to serve expressed management needs. A 35-page booklet of these commitments was developed, presented, and approved by the directorate in September 1979.

Calculating Project Schedules and Manpower

The ACSP/PYPSCAN Project team assigned to this task worked closely with the team developing the manpower calculation portion of the system. A historical data base of some 4000 projects was developed, thoroughly reviewed, and adjusted to reflect the latest processes. Schedule information and manpower expenditures were tabulated. Project variables (e.g., size, details of construction work, environmental study type process involved, weather zone, traffic volumes, etc.) were also tabulated. These data were then analyzed statistically in the computer through a whole series of linear regression combinations to find significance and identify any commonality with known variables. Output from these analyses was then reviewed rigorously by the team. This review resulted in adjusting the output of the statistical analysis and introducing the professional judgments of the team to finally arrive at agreed-on formulas for calculating timelines and manpower. This assured credibility with current methods and procedures. In the team's analysis and study of data, they found the key variables affecting project timelines and manpower requirements to be (a) project type, (b) project size, (c) weather terrain zones, (d) location, (e) environmental study, and (f) manpower categories.

The key control mechanism in PYPSCAN is a Milestone Control Plan (see Figures 4 and 5). Every project is developed and completed in three separate phases; preliminary project development, design project development, and construction. Preliminary project development includes developing and obtaining approval of conceptual features for the project and conducting and obtaining approval of the environmental impact study. Design project development includes detailed project design and contract plan development, structures design and contract plan development, and right-of-way engineering, appraisal, and acquisition. Construction encompasses all engineering inspection including structure work and contract administration activities as well as any right-of-way cleanup activities required to complete the project.

Figure 5. Milestone control plan node identification.

PHASE	NODE #	TITLE
I	10	Initiate Studies-Start Phase I
	20	Stage 1 Work Program
	40	Stage 2 Work Program
	60	Circulate Draft Project Report and Draft Envir. Doc.
	100	Submit Project Report
	111	Project Report Approval
	120	Circulate Environmental Doc.
	140	Hearings
	160	Request Project Approval
	200	Project & Envir. Doc. Approval
II		End Phase I - Start Phase II
	220	Geometric Base Maps
	221	Bridge Site Submittal
	222	Begin Bridge Design
	224	R/W Map Submittal
	225	Start Regular R/W Work
	260	Skeleton Contract Layouts
	265	Final R/W Maps
	275	General Plans
	300	District Dummy Plans
	360	Environmental Re-Evaluation
	378	Bridge PS&E
	380	District PS&E
	410	R/W Certification
	460	HQ PS&E Complete
	480	HQ Advertise
	500	Approve Contract
III		End Phase II - Start Phase III
	600	Job Complete
	700	Final Report - End Phase III

Each project phase is further defined in terms of major milestones. As shown in Figures 4 and 5, 28 major milestones have been identified with some of the milestones not calculated on minor projects where they are inappropriate, e.g., where no major environmental study, structures, and/or right-of-way are involved.

Seven basic milestone configurations are needed to distribute time and manpower across the full project timeline. Each milestone configuration has a series of formulas developed because of variations of time and manpower distribution between milestones. These formulas are further modified by factors related to the key variables discussed earlier.

The entire series of formulas for timeline and manpower calculation is loaded into the computer in the form of matrix tables. A master "decision" table matches project variables identified on the specific project and automatically selects the appropriate formulas, factors, and milestone type and performs the calculations. As noted earlier, the decision regarding development of the system was to keep the user involvement simple. To accomplish this and still produce quality information required an intensive project team effort to assure building all of the required complexities into the computer tables and calculations. Standardization has been maintained, while providing for uniqueness in terms of specific project variables. The on-line input is simple, as shown in Figure 6, which depicts the cathode ray tube screen display the user sees while inputting basic project data.

Figure 7 shows the calculation screen. The user performs the calculation by simply placing an "x" at the start date on the milestone portion of the screen and pushes the "execute" button. The computer then calculates the timeline and manpower required and displays them on the screen as dates on the milestone portion and person-years by category, spread by fiscal year.

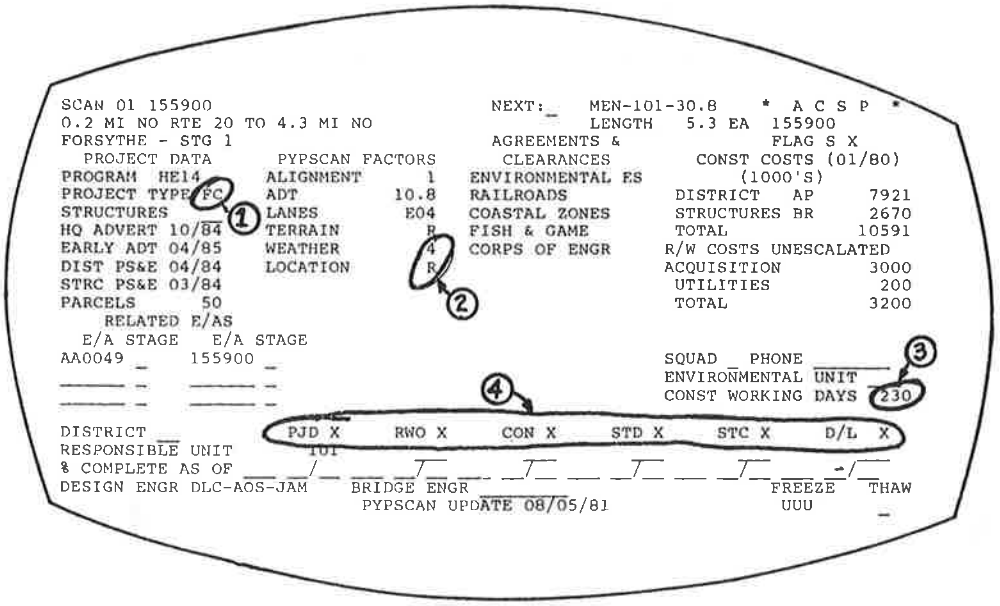
An override feature is provided to enable the user to adjust his or her schedule if either the uniqueness of the project requires any further adjustments along the timeline, or if actual progress varies from the target timeline calculated. When an override is performed, the manpower is automatically adjusted to match the overridden timeline.

During the design phase of the project (see Figure 4), three separate timelines exist. Structures design, project design, and right-of-way each have separate pathways. These are linked at key milestone points on the project design line. During the calculation process, a simple critical-path analysis is automatically performed. If either or both structures and right-of-way timelines are longer than project design, a message displays on the screen to inform the user that structures and/or right-of-way timelines are controlling and the succeeding milestones have been "adjusted by __ months".

OUTPUT REPORTS

The system now produces a whole series of management

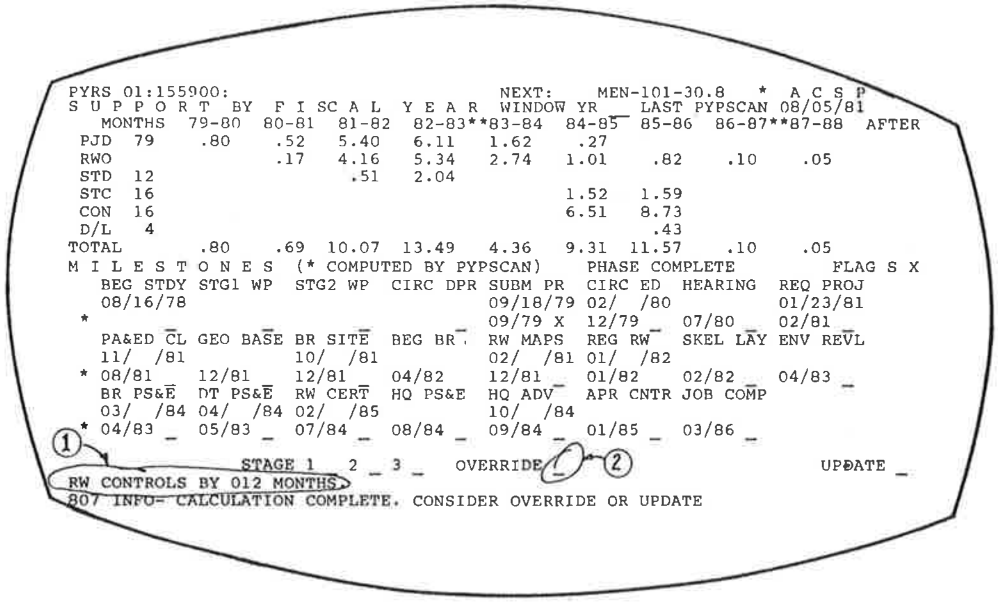
Figure 6. PYPSCAN CRT screen: basic on-line project data input screen.



```
SCAN 01 155900                               NEXT:_    MEN-101-30.8     *  A C S P  *
0.2 MI NO RTE 20 TO 4.3 MI NO                          LENGTH   5.3 EA  155900
FORSYTHE - STG 1                             AGREEMENTS &                  FLAG S X
  PROJECT DATA        PYPSCAN FACTORS          CLEARANCES          CONST COSTS (01/80)
PROGRAM  HE14       ALIGNMENT          1   ENVIRONMENTAL ES             (1000'S)
PROJECT TYPE FC     ADT             10.8   RAILROADS               DISTRICT   AP      7921
STRUCTURES          LANES            E04   COASTAL ZONES           STRUCTURES BR      2670
HQ ADVERT 10/84     TERRAIN            R   FISH & GAME             TOTAL             10591
EARLY ADT 04/85     WEATHER            4   CORPS OF ENGR          R/W COSTS UNESCALATED
DIST PS&E 04/84     LOCATION           R                          ACQUISITION         3000
STRC PS&E 03/84                                                    UTILITIES           200
PARCELS       50                                                   TOTAL              3200
    RELATED E/AS
  E/A STAGE    E/A STAGE
AA0049 _     155900 _                                          SQUAD _  PHONE _______
______ _     ______ _                                          ENVIRONMENTAL UNIT ___
______ _     ______ _                                          CONST WORKING DAYS  230

DISTRICT __            PJD X      RWO X      CON X      STD X      STC X      D/L  X
RESPONSIBLE UNIT        101
% COMPLETE AS OF ___ __/__ ___ __/__ ___ __/__ ___ __/__ ___ __/__ ___ __/__
DESIGN ENGR DLC-AOS-JAM    BRIDGE ENGR ______                         FREEZE   THAW
                            PYPSCAN UPDATE 08/05/81                    UUU       _
```

Figure 7. PYPSCAN CRT screen: on-line PYPSCAN calculation for project schedules and manpower.



```
PYRS 01:155900:                              NEXT:    MEN-101-30.8    *  A C S P
S U P P O R T  BY  F I SC A L  Y E A R  WINDOW YR __ LAST PYPSCAN 08/05/81
   MONTHS  79-80  80-81  81-82  82-83**83-84  84-85  85-86  86-87**87-88  AFTER
 PJD  79    .80    .52   5.40   6.11   1.62    .27
 RWO               .17   4.16   5.34   2.74   1.01    .82    .10    .05
 STD  12                  .51   2.04
 STC  16                                      1.52   1.59
 CON  16                                      6.51   8.73
 D/L   4                                              .43
TOTAL       .80    .69  10.07  13.49   4.36   9.31  11.57    .10    .05
M I L E S T O N E S  (* COMPUTED BY PYPSCAN)    PHASE COMPLETE         FLAG S X
   BEG STDY STG1 WP  STG2 WP  CIRC DPR SUBM PR  CIRC ED  HEARING  REQ PROJ
   08/16/78                            09/18/79 02/  /80          01/23/81
 *                                     09/79 X  12/79 _  07/80 _  02/81 _
   PA&ED CL GEO BASE BR SITE  BEG BR   RW MAPS  REG RW   SKEL LAY ENV REVL
   11/  /81          10/  /81          02/  /81 01/  /82
 * 08/81 _  12/81 _  12/81 _  04/82    12/81 _  01/82    02/82 _  04/83 _
   BR PS&E  DT PS&E  RW CERT  HQ PS&E  HQ ADV   APR CNTR JOB COMP
   03/  /84 04/  /84 02/  /85          10/  /84
 * 04/83 _  05/83 _  07/84 _  08/84 _  09/84 _  01/85 _  03/86 _

                STAGE 1   2 _ 3 _    OVERRIDE _                        UPDATE _
RW CONTROLS BY 012 MONTHS
807 INFO= CALCULATION COMPLETE. CONSIDER OVERRIDE OR UPDATE
```

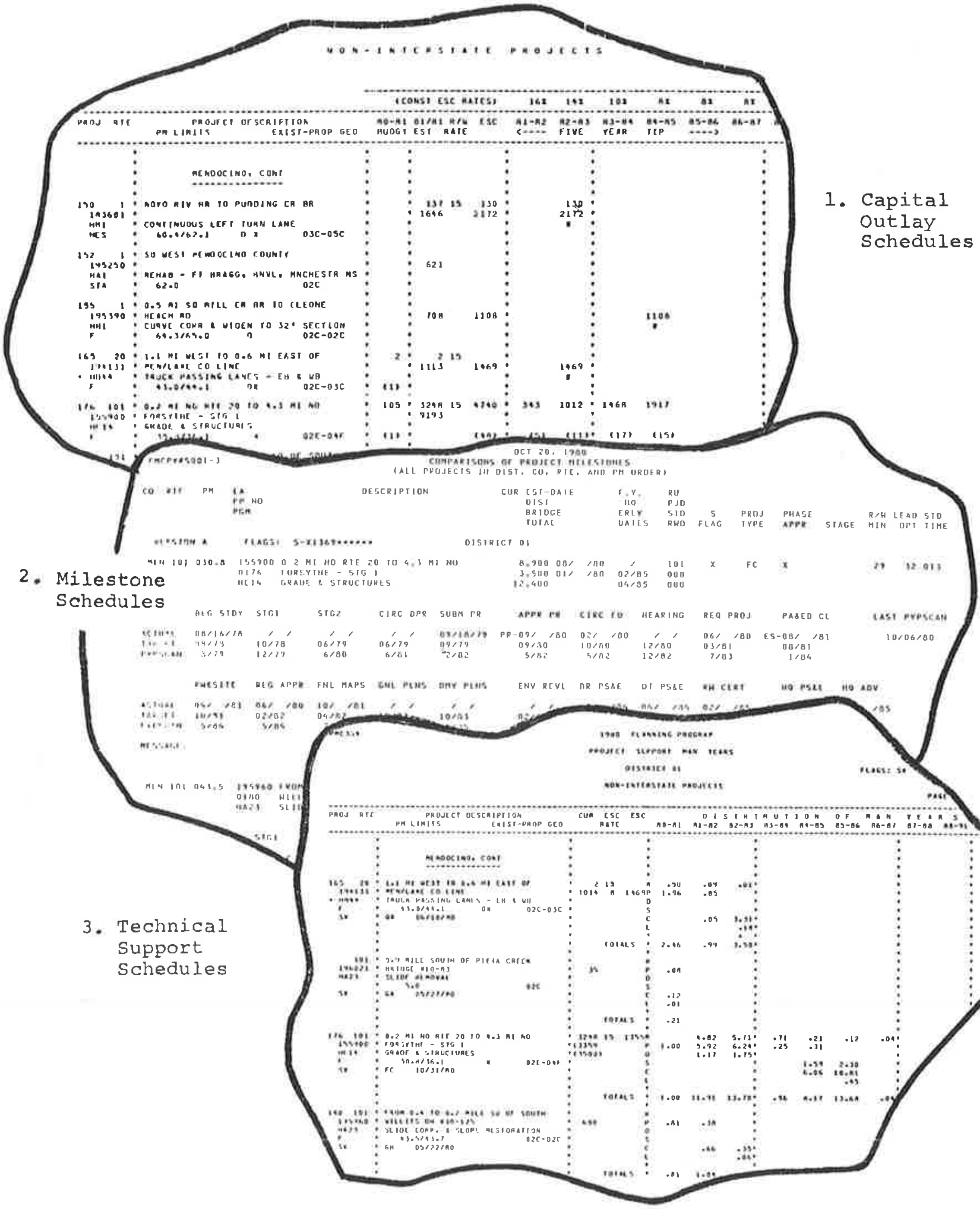
reports for use in resource planning, resource programming, and tracking planned against accomplished. What will be discussed and shown in the following section is an abbreviated version of system output reports to provide the reader with just a flavor of types of reports available. It should also be understood that the system has been designed to produce reports from the highest to lowest levels of management. Multiple sorts are available on practically any combination of items or features included in the system. A few of the special manpower planning and milestone selection reports have become instant "best sellers."

Capital Scheduling Plan

The stated objective of the task force in 1979 was to automate the capital scheduling plan. In May 1980, when the first unit of the new system was implemented and approximately 3000 projects had been calculated and loaded into the system, the capital scheduling plan was automated. A whole series of management reports became available at that time. An example of basic reports that were available are shown in Figure 8 and noted briefly below:

1. Support--Any combination of work functions may be selected for the support series of reports (see Figure 8). The format, a listing by project, is the same as that used for the capital outlay schedule except that the values shown are person-years rather than dollars. The person-year matrix is broken down by work function and by fiscal year as shown on the PYRS screen (Figure 8).
2. Milestones--A sample of a project milestone report appears in Figure 9. Any combination of projects and/or sorts is available on this report. This is a basic project delivery report. Periodic statewide monitoring is conducted by using this report and other "exception" reports. In addition

Figure 8. Capital scheduling plan reports: dollars, time, and people.



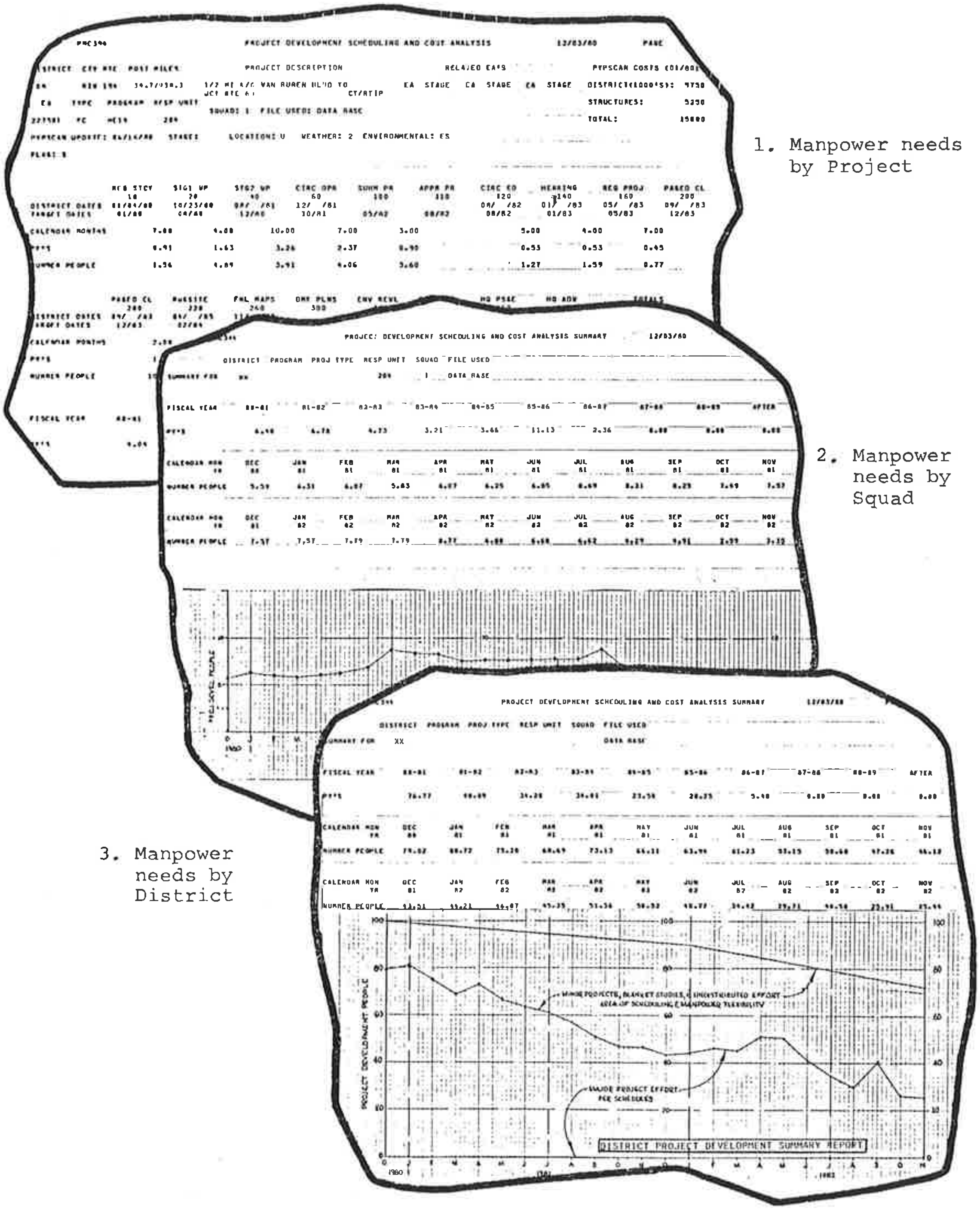
to basic information, there are three rows of dates shown and up to 28 milestones reported on each report. The first row represents the accomplished status dates or project manager's expectations. The second row is the modified PYPSCAN timeline on which the manpower is distributed. These are also the dates that the project manager is held accountable for meeting. The third row of dates shown is the unmodified pure PYPSCAN calculated dates that are used to compare dates for consistency and checking formula credibility.

Special Reports: Manpower

Special reports can be generated by selecting special computer sorts of data. Possibilities are numerous. One of the most popular reports, especially to district management, is our version of production planning summary reports. These reports are provided in series for the various levels of management. These reports can be provided for each of the manpower categories, e.g., structures design, construction engineering, and right-of-way. The series for project development and design engineering is shown in Figure 9. All of these reports are "on demand," usually deliverable in from one to two hours following a request.

1. Project-level production reports--This report

Figure 9. Special reports on manpower production: hierarchy of reports at project, squad, and district levels for project development engineering.

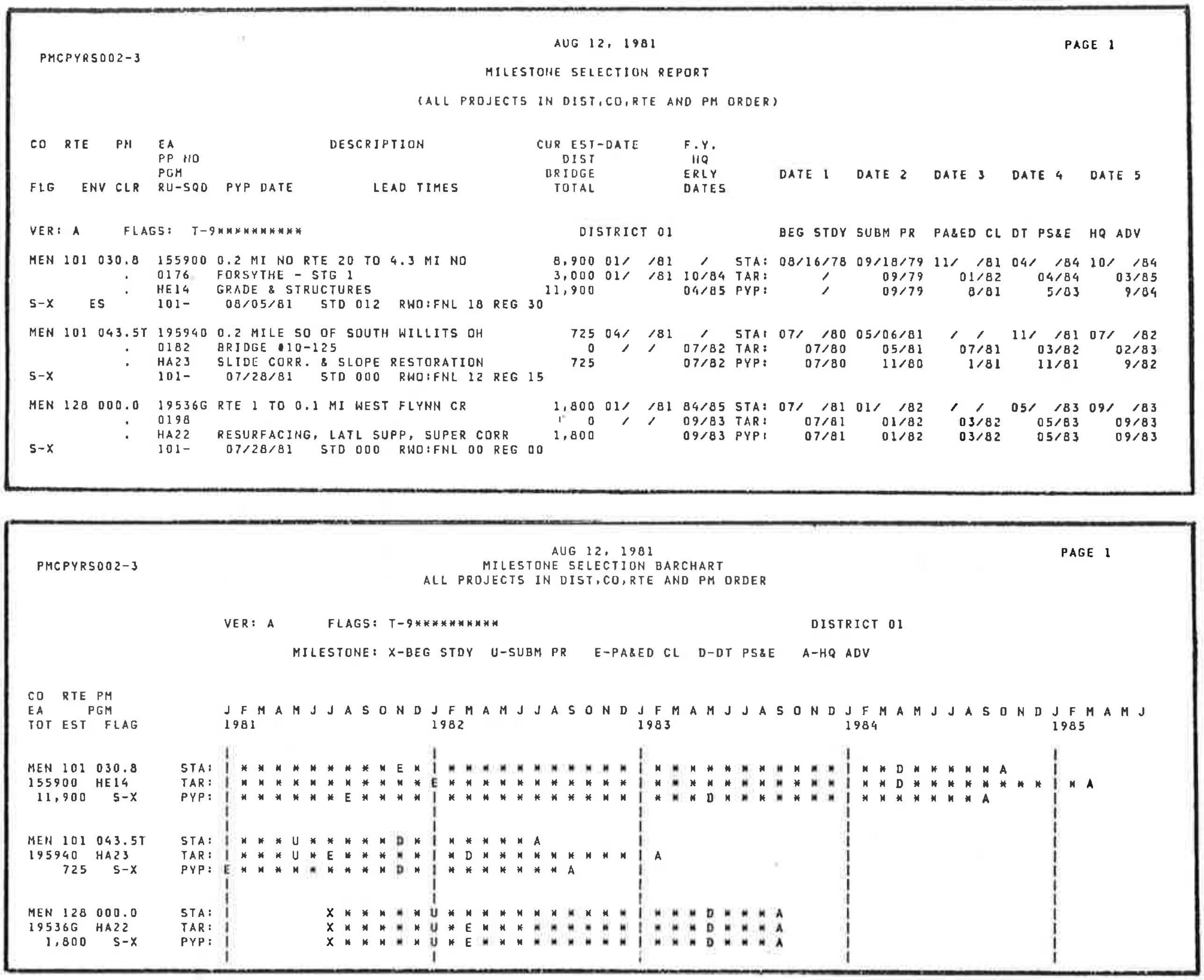


is the basic detail "planning" report provided to the project development project manager. As shown, data are detailed for people and time across the full span of project development activities. Note that on the "number people" line, a calculation is shown to indicate the average number of project development people needed across the timeline to keep the project on schedule.

2. Design squad or unit summary report--Shown in the center portion of Figure 9 is a basic squad-level summary report. Normally, a project manager in project development will have a number of projects in various stages of development at any one time. The data calculated on this report are a month-by-month, two-year projection, beginning in the month of the request. It summarizes people needs on all projects assigned to the squad. The graphic display shown at the bottom of the report (now being machine plotted) shows the two-year workload requirements to keep all of the projects assigned to the squad on schedule. This information is used for workload leveling and for project scheduling adjustments.

3. Design section summary report--Shown at the bottom of Figure 9 is a district-level workload summary report. Such reports summarize projections

Figure 10. Special reports for timelines: milestone selection and accompanying bar chart display.



```
                                                       AUG 12, 1981                                                    PAGE 1
PMCPYRS002-3
                                                MILESTONE SELECTION REPORT

                                         (ALL PROJECTS IN DIST,CO,RTE AND PM ORDER)


CO   RTE   PM  EA                DESCRIPTION             CUR EST-DATE   F.Y.
               PP NO                                        DIST         HQ
               PGM                                         BRIDGE       ERLY        DATE 1   DATE 2   DATE 3   DATE 4   DATE 5
FLG   ENV CLR  RU-SQD  PYP DATE          LEAD TIMES         TOTAL       DATES


VER: A     FLAGS:  T-9**********                          DISTRICT 01              BEG STDY SUBM PR  PA&ED CL DT PS&E  HQ ADV

MEN 101 030.8  155900 0.2 MI NO RTE 20 TO 4.3 MI NO      8,900 01/  /81   /   STA: 08/16/78 09/18/79 11/  /81 04/  /84 10/  /84
             . 0176   FORSYTHE - STG 1                   3,000 01/  /81 10/84 TAR:        /    09/79    01/82    04/84    03/85
             . HE14   GRADE & STRUCTURES                11,900          04/85 PYP:        /    09/79     8/81     5/83     9/84
S-X    ES      101-    08/05/81   STD 012  RWO:FNL 18 REG 30

MEN 101 043.5T 195940 0.2 MILE SO OF SOUTH WILLITS OH      725 04/  /81   /   STA: 07/  /80 05/06/81   /  /   11/  /81 07/  /82
             . 0182   BRIDGE #10-125                         0   /  /   07/82 TAR:    07/80    05/81    07/81    03/82    02/83
             . HA23   SLIDE CORR. & SLOPE RESTORATION      725          07/82 PYP:    07/80    11/80     1/81    11/81     9/82
S-X            101-    07/28/81   STD 000  RWO:FNL 12 REG 15

MEN 128 000.0  19536G RTE 1 TO 0.1 MI WEST FLYNN CR      1,800 01/  /81 84/85 STA: 07/  /81 01/  /82   /  /   05/  /83 09/  /83
             . 0198                                          0   /  /   09/83 TAR:    07/81    01/82    03/82    05/83    09/83
             . HA22   RESURFACING, LATL SUPP, SUPER CORR 1,800          09/83 PYP:    07/81    01/82    03/82    05/83    09/83
S-X            101-    07/28/81   STD 000  RWO:FNL 00 REG 00
```

```
                                                     AUG 12, 1981                                          PAGE 1
PMCPYRS002-3                                 MILESTONE SELECTION BARCHART
                                       ALL PROJECTS IN DIST,CO,RTE AND PM ORDER


                        VER: A       FLAGS: T-9**********                           DISTRICT 01

                              MILESTONE: X-BEG STDY  U-SUBM PR   E-PA&ED CL   D-DT PS&E    A-HQ ADV


CO  RTE PM
EA      PGM             J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
TOT EST  FLAG           1981                    1982                    1983                    1984                    1985

                        |                       |                       |                       |                       |
MEN 101 030.8      STA: | * * * * * * * * * E * | * * * * * * * * * * * | * * * * * * * * * * * | * * D * * * * * A     |
155900  HE14       TAR: | * * * * * * * * * * * E * * * * * * * * * * * | * * * * * * * * * * * | * * D * * * * * * * * | * A
 11,900   S-X      PYP: | * * * * * * E * * * * | * * * * * * * * * * * | * * * D * * * * * * * | * * * * * * * A       |
                        |                       |                       |                       |                       |
                        |                       |                       |                       |                       |
MEN 101 043.5T     STA: | * * * U * * * * * D * | * * * * * A           |                       |                       |
195940  HA23       TAR: | * * * U * E * * * * * | * D * * * * * * * * * | A                     |                       |
   725   S-X       PYP: E * * * * * * * * * D * | * * * * * * * A       |                       |                       |
                        |                       |                       |                       |                       |
                        |                       |                       |                       |                       |
MEN 128 000.0      STA: |           X * * * * * U * * * * * * * * * * * | * * * D * * * A       |                       |
19536G  HA22       TAR: |           X * * * * * U * E * * * * * * * * * | * * * D * * * A       |                       |
  1,800   S-X      PYP: |           X * * * * * U * E * * * * * * * * * | * * * D * * * A       |                       |
                        |                       |                       |                       |                       |
```

for multiple squads at the district level. They also provide two-year snapshots for top-level district managers to "look out front" for significant problems that they can address early and to identify opportunities for leveling their entire district design engineering workload.

Special Reports: Milestones

We have found that timeline analysis has been highly desired by all levels of management. We developed a five-milestone selection report for this purpose (Figure 10). This allows a manager to select any group of five milestones from the 28 in the system. With the multiple sort capability available in the system, the manager can design a report listing to array any specific section selected along the timeline for an entire group of projects. The produced listings will quickly reveal progress to date, how far ahead or behind the work effort is, and how much is yet to be accomplished. Workload concentrations for any series of activities can also be readily identified. Attendant problems can then be predicted so that early corrective action can be taken. A subroutine that plots a bar timeline across the same selected five milestones is also available (see Figure 10). It is the same type of information as on the data report, but has the advantage of a graphic format.

At present, approximately 25 percent of the major projects in our current five-year plan lack project reports (first major milestone event). We are using this report to analyze this process to see where either processes might be expedited or reassignments made to accelerate delivery.

COSTS

We have recently reviewed our costs to date to develop this system to its current status (slightly more than two years). There has been very little fulltime involvement. Most of the project team's efforts have been parttime with spurts of concerted effort over short time spans. Some members of the project team have other, regular duties directly related to capital scheduling plan type analysis. Their time has been discounted except where identified with specific development activities. The costs are as follows:

Item	Cost
People	$525 000 (equivalent of 15 person-years)
Machinery	$100 000 (computer plus overhead assessment)
Total	$625 000 (for two years with about $250 000 remaining,
Maintenance	$70 000/year (mainly for statistical analysis and system updating)

SAVINGS

The most notable savings are in the budget development area. The new system virtually eliminates most of the old decentralized, manpower-intensive process. We are now in the second budget iteration since implementation of the new system and we estimate an effort savings over the past two years of about $875 000 with a continuing savings of at least $450 000/year into the future. The improvement in the quality of budget information provided is somewhat measured by the plaudits that the department has received from the Legislative Analysts.

BENEFITS

In addition to the quality of management information improvements and services resulting from the system, we conservatively estimate that a 5 percent increase in productivity per year is being realized due to the structured process provided with this new system and should be assumed as a resultant quantifiable benefit. We estimate that this benefit amounts to about a $10 million saving in people costs or an increased capability to an additional $45 million saving in accelerated projects as long as staffing remains constant.

SUMMARY AND CONCLUSION

Managing transportation program resources during this era of limits is a very difficult and complex operation at best. The need for an engineered systems approach, complimented by a comprehensive management information system to provide quality information for decisionmaking purposes, cannot be overstressed.

The new system developed in California has not been offered as a decisionmaking panacea--systems do not make decisions, people make decisions. This system has been designed with a focus directed at the effective management of productivity through informed and timely decisionmaking to make things happen. It has been developed for use in resource management planning and then to measure the effectiveness in carrying out that plan. With implementation of the first unit just one year ago, the system has been used exclusively in a number of resource planning opportunities. The most notable were the following:

1. Used to develop a top-level management evaluation report of the 1980 five-year state transportation improvement program (1980 five-year program was developed prior to system implementation). The report informed the directorate that about one-third ($600 million) of the program was not deliverable as scheduled, and of that total approximately $200 million in projects were not even deliverable within the five years. The evaluation concluded that process times, lagging productivity, and overoptimism in project scheduling were major contributors to the problem along with a staff distribution, not shortage, problem.
2. Used to establish a deliverable 1981 five-year state transportation improvement program.
3. Used to adjust the department's 1980-1981 budget and to develop the 1981-1982 budget.
4. Used to identify opportunities for project reassignment to the centralized design pool to mitigate the staff imbalance problem and to improve program delivery.
5. Used in a number of what-if exercises.

The system is not complete, but we are well on our way to providing a valuable management tool. In conclusion, acknowledgment of the strong support and "push from the top" by the director and top staff, as well as confidence by all organizational levels in the system, has been essential for success. Finally, recognition that the outstanding effort by the project team involved in this development was key to its delivery in the short time allocated.