Improved Highway Program Management Through Use of Integrated Information Systems

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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-

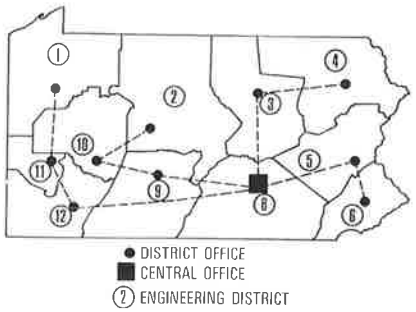


Figure 1. Location of state's 11 engineering districts and representative communications network related to information management systems.

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 under-

taken 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:

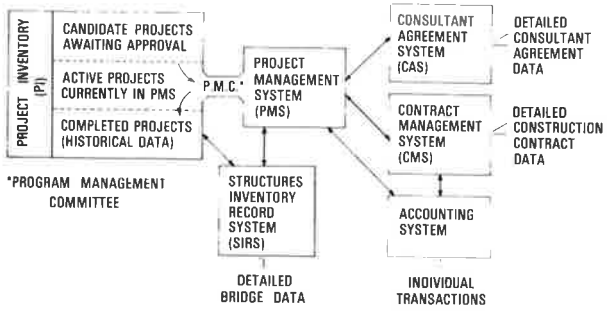
1. Monitor data on the inventory, inspection, repair, and condition of all bridges (structures) in the state greater than or equal to 8 ft in length,
2. Generate computer tape files of bridge data to meet FHWA reporting requirements, and
3. Provide a means of summarizing and reporting structures data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



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.

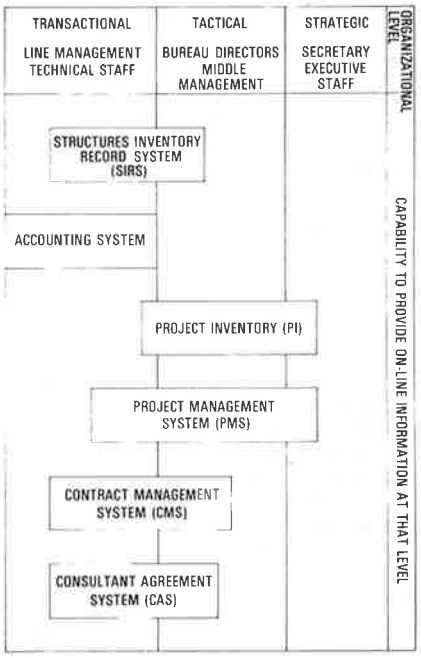
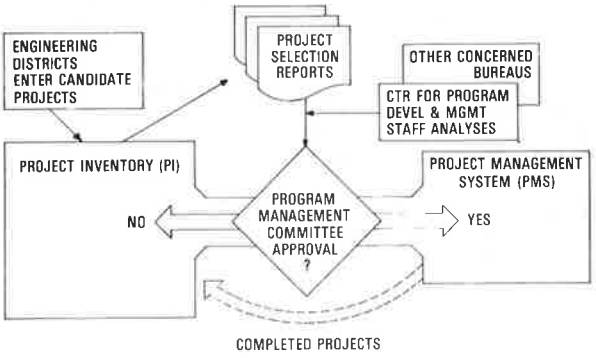


Figure 4. Overview of project selection and approval process.



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.

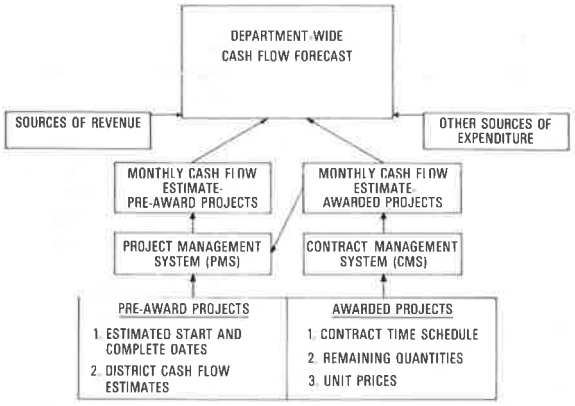
Cash Flow Forecasting

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.

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Development of Priority Program for Roadside Hazard Abatement

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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