A Microcomputer Management System for Setting Highway Priorities and Scheduling Improvements

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Microcomputer technology offers significant potential to help in assessing infrastructure needs, analyzing priorities and tradeoffs, and managing maintenance programs and capital improvement projects at state and local levels. Illustrating this potential is a system now being used by the Metropolitan District Commission (MDC), a state agency responsible for 153 mi of commuter parkways and recreational roads in the Boston area. Operating on IBM personal computers with a commercial database manager, the system stores and manages data on pavement condition, traffic volume, bridges, signals, street lighting, sidewalks, curbing, and other roadside features. A single menu- and screen-oriented framework gives easy access to all of this information for viewing and updating, and for retrieval through standardized reports. Program development capabilities are provided for defining capital improvement projects, estimating their costs, setting priorities, and scheduling. The speed and flexibility of off-the-shelf hardware and software has made the initial system design and subsequent enhancements very efficient and responsive to MDC needs. By developing the system through many successive prototypes, evolving from the first quick-and-dirty demonstration up to the current polished production system, it has been possible for MDC staff to become comfortable with computers while simultaneously becoming informed participants on the design team. This development has led to a more satisfactory and useful final product.

The Metropolitan District Commission (MDC) is a state agency responsible for a wide-ranging system of parks, waterways, recreational facilities, beaches, and parkways in the metropolitan Boston area. Initially developed to provide access to this system for residents of the area, the 153-mi parkway network was designed to complement the park system, with roadways different in character from other streets and highway systems in and around the Boston area. The parkways are tree lined and landscaped, and they provide a visual relief for the motorist accustomed to commercial surroundings and purely functional facilities.

Over the years, the parkway system has also become an integral part of the regional highway network, including some of the area's busiest commuter routes. This integration has resulted in the need for the MDC to take on the added responsibility of maintaining a physically sound and functionally safe system in addition to providing aesthetic and environmental relief for the area.

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Because a substantial capital investment has been made in the construction of parkways, the MDC has recognized that it is essential to expend the necessary resources to maintain and rehabilitate those capital assets in order to avoid their deterioration to the point where complete reconstruction or replacement is necessary. As a result, the MDC felt that it needed to improve the data available to assess funding needs and to develop procedures to evaluate alternative strategies for preserving the system in the most cost-effective manner over the long run.

To develop a systematic process and the necessary data to produce a priority program and schedule of improvements, the MDC has developed and implemented a parkway management system (PMS). The purpose of the PMS is to provide the technical and management tools needed to

- Develop a systematic approach to the management of the parkway system,
- Document the needs of the system in a format that will support the MDC objective to fund needed improvements over both the short and long terms,
- Use the available funds in the most cost-effective manner possible and schedule projects consistent with MDC priorities and resource constraints, and
- Provide measures of improvements and progress made in the implementation of the program.

In addition to developing the data and procedures necessary to accomplish these tasks, the PMS also provides the basis for a cycle of activities that can be followed to update the database and capital program every 2 years. That updating cycle, whose timing must be consistent with the state's biennial highway bonding program, will ensure that the MDC has all the data necessary to support funding requests for future years and to adequately track and document its progress toward a better parkway system. In this paper, the pavement rehabilitation and roadside features portion of the PMS is emphasized, but the system also includes databases for bridges, traffic signals, and street lighting. A long-term objective is to extend the capital programming process described here to include these additional elements of the parkway system.

The PMS supports a computer-aided decision-making process. Capital programming decisions in this process are made by the informed judgments of managers and engineers, using their experience and familiarity with the parkway network, the input of elected officials and the general public, and computerized data and analytical aids. An effective programming process should fully use all of these resources in order to make the best possible programming decisions. However, in this paper the microcomputer system developed to support this broader program decision-making process is emphasized.

OVERVIEW OF THE SYSTEM

Implemented on an IBM personal computer, the PMS takes advantage of the power and user friendliness of microcomputer software to store and retrieve parkway-related data in a simple, fast, and secure manner. The decision to use a microcomputer was made early in the process; in fact, trying to implement a system of this kind on a more expensive machine would be quite impractical for an agency this small. Although many different personal computer models are available that have the technical capability needed for this application, the IBM system was chosen to maintain compatibility with other machines already owned by the MDC. To augment the storage capacity of the machine, it has been upgraded to 640 kilobytes of internal memory and a 40-megabyte hard disk, of which about half is used for the PMS and half is used for other, unrelated applications.

The SMART data manager was chosen as the application development environment for the system, to provide the necessary user interface and database management capabilities. The wide range of SMART features and its ability to generate turnkey systems have made possible implementation of the entire PMS within this one environment, making the system efficient and flexible. Although the system speed might have been improved by the use of a more traditional high-level language, the performance of SMART has been more than acceptable for this application.

To the end user, the PMS appears as a tree or hierarchy of menus (Figure 1), the first of which appears on the screen whenever the computer is turned on. The PMS is part of a larger hierarchy that includes databases (not described in this paper) for traffic signals, bridges, street lighting, and landscaping. Within the PMS, there is a complete inventory of parkway features and pavement condition, a separate file for potential pavement rehabilitation projects, and a set of analytical aids for program development.

In its mechanical aspects, the system has a simple, uniform set of rules that govern all menu selections and activities. Figure 2 shows a typical menu. It takes only a few keystrokes

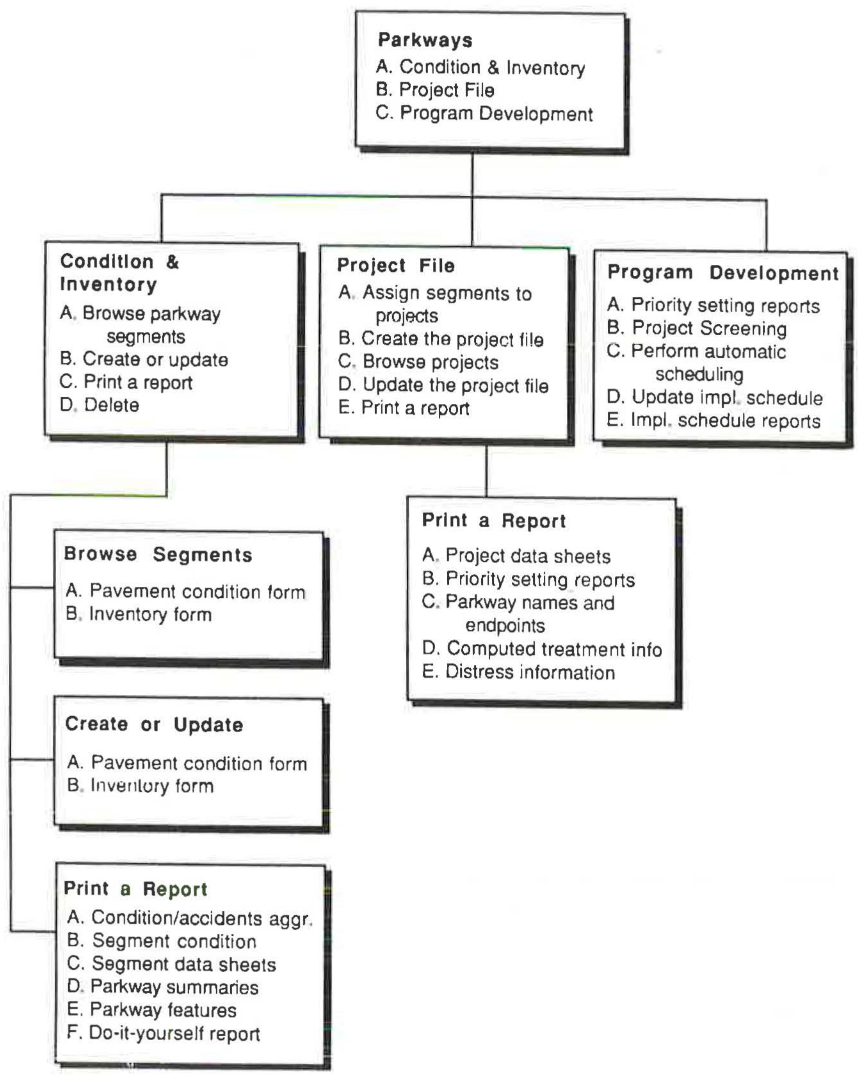

FIGURE 1 PMS menu structure.

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                                              05/23/86  11:26:06
  Parkways
    Parkway Conditions and Inventory
      Print a report


           ▮ A. Pavement condition and accidents aggregation
             B. Segment condition
             C. Segment data sheets
             D. Parkway summaries
             E. Parkway features
             F. Do-it-yourself report
             G. Go to Parkway Conditions and Inventory Menu


    Please press the spacebar to move the cursor to your selection,
      then press the Enter key.
```

FIGURE 2 Example of a menu.

to move upward or downward through the menu tree. Upon selection of any leaf of the tree, the PMS presents a screen, such as the one shown in Figure 3, describing what the selection does and asking for more information on what action is desired. With these features, a beginning user can quickly and easily take a tour of the PMS to learn about its capabilities. Even people with no previous computer experience have found that it takes no more than 1 hr to 1 day to become comfortable with navigating through the system and requesting reports.

The parkway inventory and pavement condition database contains a large amount of information on pavement defects, traffic volume, accident rates, geometrics, and roadside features on all 655 segments of the parkway network. The following is a complete listing of the items available:

IDENTIFIER INFORMATION
- MDC parkway number
- MDC segment number
- Traffic direction
- Parkway name
- From street
- To street
- Auto route number

```
                SEGMENT CONDITION REPORT

    This command prints a report on parkway segment  Sort by:
    conditions, with the data items shown at right.
                                                       Cancel
    Please choose the data item on which you would     Parkway_Number
    like the report sorted. Use the spacebar to        Parkway_Name
    highlight your choice, then press the Enter        Segment_Miles
    key.                                               ADT
                                                       Function_Class
                                                       PCR
                                                       Condition_Type
                                                       PSI
                                                       Accidents
                                                       Project_Number
```

FIGURE 3 Example of an input screen.

DIMENSIONS
- Station number (beginning and end)
- Segment length
- Traveled way width
- Number of lanes
- Square yards
- Lane miles
- Centerline miles

JURISDICTION
- City or town
- County
- MDC division
- MDC district
- MDC region
- MDC police district
- MDPW road number
- MDPW district number
- Federal aid system class
- Federal aid route number
- Legislative district
- Project number

TRAFFIC
- Functional class
- Street operation
- Average daily traffic (ADT)
- Year of latest traffic count
- Truck percent of ADT
- Vehicle miles traveled
- ADT per lane
- Posted speed limit
- Truck and bus exclusion

ACCIDENTS
- Count (fatal, injury, other)
- Rate (fatal and injury, total)

ROADWAY FEATURES AND CHARACTERISTICS
- Ramps (length, width, area in square yards)
- Shoulders (material, width)
- Parking lane width
- Adjacent parking (material, length, width, area in square yards)
- Curb reveal
- Number of signalized locations
- Designated bike route
- Number of undercrossings and overcrossings
- Minimum posted vertical clearance
- Number of railroad crossings at-grade
- Tangent or curved
- Terrain type
- Culvert (height, width)
- Special pavement features

ROADSIDE FEATURES
- Sidewalk (material, location, condition, width)
- Guard rail (material, length)
- Curbing (type, condition, curb cuts, reveal)
- Traffic islands
- Median (width, material)
- Sign count (warning, regulatory, guide)

LIGHTING, SIGNALS, DRAINAGE, UTILITIES
- Lighting (occurrence, pole material)
- Drainage type
- Overhead utilities
- Underground utilities

PAVEMENT CONDITION INDICES
- Deduct points for each distress
- Total deduct points (load-related, non-load-related)
- Pavement condition rating (PCR)
- Condition type
- Present serviceability index (PSI)

LAND USE AND TREES
- Primary adjacent land use
- Bodies of water within 100 ft
- Trees (type, density)

PAVEMENT DISTRESSES
- Alligator cracking (severity, extent)
- Longitudinal cracking (severity, frequency, extent, whether sealed)
- Transverse cracking (width, number, whether sealed)
- Block cracking (width, extent, whether sealed)
- Rutting (depth, extent)
- Rippling, shoving, and corrugation (severity, extent)
- Raveling (severity, extent)
- Bleeding (severity, extent)
- Patching (condition, extent)
- Crown type
- Number of potholes
- Apparent drainage problems
- Edge damage (severity, extent)

OTHER INFORMATION
- Date updated (condition, inventory)
- Prepared by whom (condition, inventory)
- Comments (condition, inventory)

Because of its unique dual role of serving recreational and commuter traffic, MDC data needs and priorities are different from those of most highway agencies, placing particular emphasis on landscaping, roadside features, environmental concerns, and the individual demands of the 30 cities and towns served by the network.

All data entry and editing in the PMS is performed on easy-to-use data entry screens, with extensive error-trapping and consistency checks. The entire database is designed to be updated once every 2 years, and individual parkway segments can be updated at any time in this cycle as rehabilitation projects are completed. A complete set of organizational procedures has been established to ensure accurate and timely data flow from the various sources within the MDC to a central PMS coordinator, who regulates the quality of data, enters them into the computer, and takes whatever actions are necessary to keep the biennial updating cycle on schedule.

SYSTEM DESIGN PROCESS

Before developing the PMS, MDC had no previous experience with computer support of its capital programming process, and many engineers who needed to use the system had little computer experience. As a result, the system design process was a unique opportunity both to demystify the computer system and to provide ongoing staff training. A flexible design process was needed that could serve to educate MDC managers and engineers while simultaneously allowing them to participate fully in the design of the system.

The solution to this dilemma—and the key to the ultimate usefulness and acceptability of the final system—was an incremental design process featuring a succession of prototypes, starting with an initial quick-and-dirty demonstration and converging on the current polished production system. In all, three completely new formal prototypes and at least five informal upgrades were produced over the 12-month design period. Using traditional management information system design tools and methodologies would make such a process inefficient and expensive; but with the power and flexibility of the microcomputer database manager, even major changes to the system could be made on short notice.

Availability of prototypes early in the process had a number of unusual but beneficial effects. It meant that the training phase of the project had to begin even before the agency owned the computer on which the PMS was eventually implemented. It also meant that several working prototypes were available before most of the data were collected. The early availability of training allowed several MDC staff members to learn to use the software application development environment, giving them the knowledge and confidence to participate in major design decisions. Finally, for both management and staff, the ability to react to something workable and concrete early in the process reduced the anxiety that often accompanies the introduction of new computer systems.

ANALYSIS CAPABILITIES

The analysis capabilities developed as part of the PMS were designed to support a computer-aided decision-making process. Specific capabilities focused on the analysis of existing conditions, the development and evaluation of proposed pavement rehabilitation projects and the development of short- and long-run investment programs.

Figure 4 shows schematically the cycle of activities included in the capital programming process. At the beginning of the cycle is a data collection effort that includes a wide range of information on

- Physical data, mostly computerized, including pavement condition, roadside features, geometrics, traffic volumes, and most of the other data items described in the listing for the PMS.

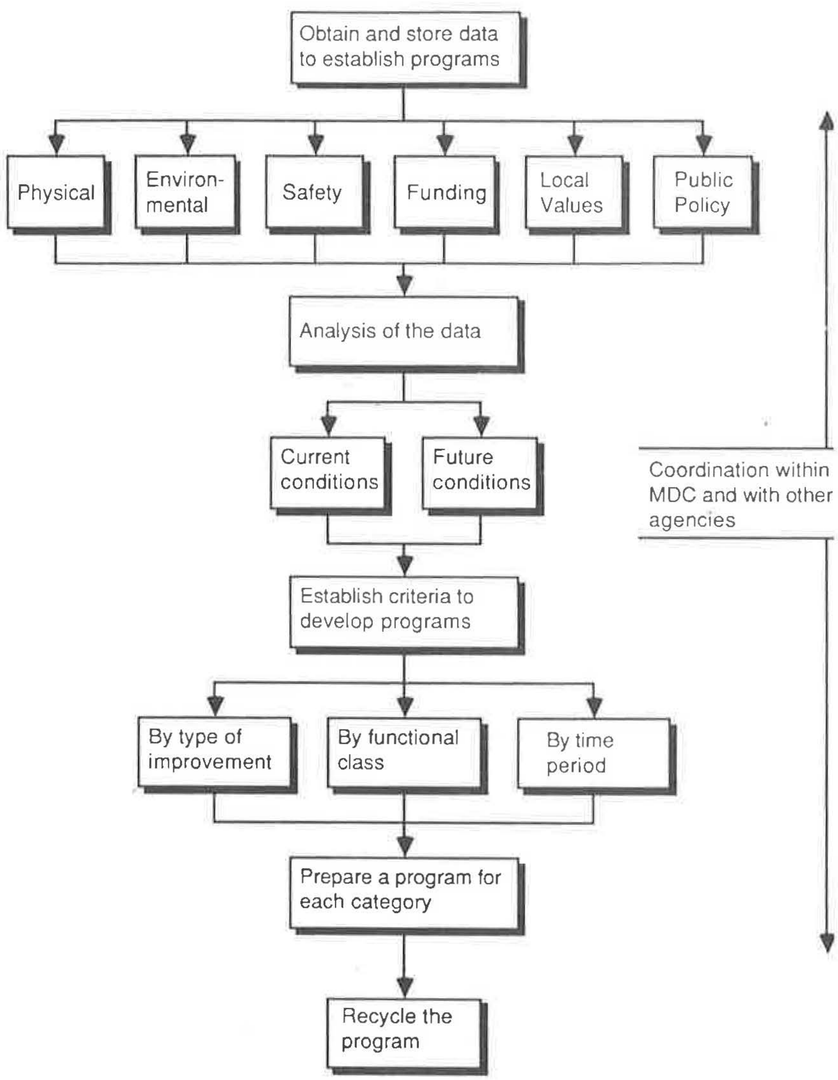

FIGURE 4 Basic elements of the programming process.

- Environmental data such as trees, land use, and roadside features, as well as noncomputerized information on future MDC plans for parkland development.
- Safety data, most notably accident rates, which are compiled by the metropolitan police and entered from there into the PMS once every 2 years.
- Assessment of funding availability that, because of the absence of hard funding limitations, consists of strategies and subjective information on ways of justifying budget requests to the state legislature and assuring steady future flows of adequate funding.
- Local values, especially data that can analyze the allocation of resources among communities and the degree to which parkway standards fit into the surrounding neighborhoods.
- Public policy considerations, a catch-all category that includes the relationships among projects of different agencies, as well as a knowledge of legislative concerns that govern the acceptability of any proposed bond authorization package.

With this information in hand, it is possible to analyze the existing conditions of the parkway network, to assess the progress made since the previous 2-year cycle and to formulate a strategy for the next biennium. The first of these actions is especially important to provide a quantitative indication of the impact of previous capital program decisions. For instance, the PMS contains a pavement condition rating (an indicator of visible pavement defects) and a present serviceability index (an indicator of road roughness or ride quality) that can be tracked over time to show whether a steady increase in average pavement condition has taken place.

An assessment of existing conditions can also help in developing criteria or guidelines for the next capital program, by pointing out the types of deficiencies that currently exist in the system. For instance, the PMS can produce standard reports that show the distribution of pavement condition, traffic volumes, or accident rates by city or town, by functional class, and by maintenance district. Other standard reports are available that show detail about individual parkways or parkway segments, including free-form commentary describing complaints that have been received from the general public or elected officials, or field inspections performed by staff engineers. These features of the computer system help to cut through the vast quantities of data available, bringing out clearly and effectively the conclusions that are most interesting and relevant to decision makers.

The culmination of each biennial cycle, and the most time-critical element of the process, is the preparation of a bond authorization request, which requires the explicit definition of projects and explicit decisions about priorities. Although the program of projects for the 2-year cycle is the most urgent product of this effort, it is also convenient and important to develop at the same time a tentative program for the following 4 years, to act as a guide—not a commitment—for future internal planning efforts. This program would help to ensure

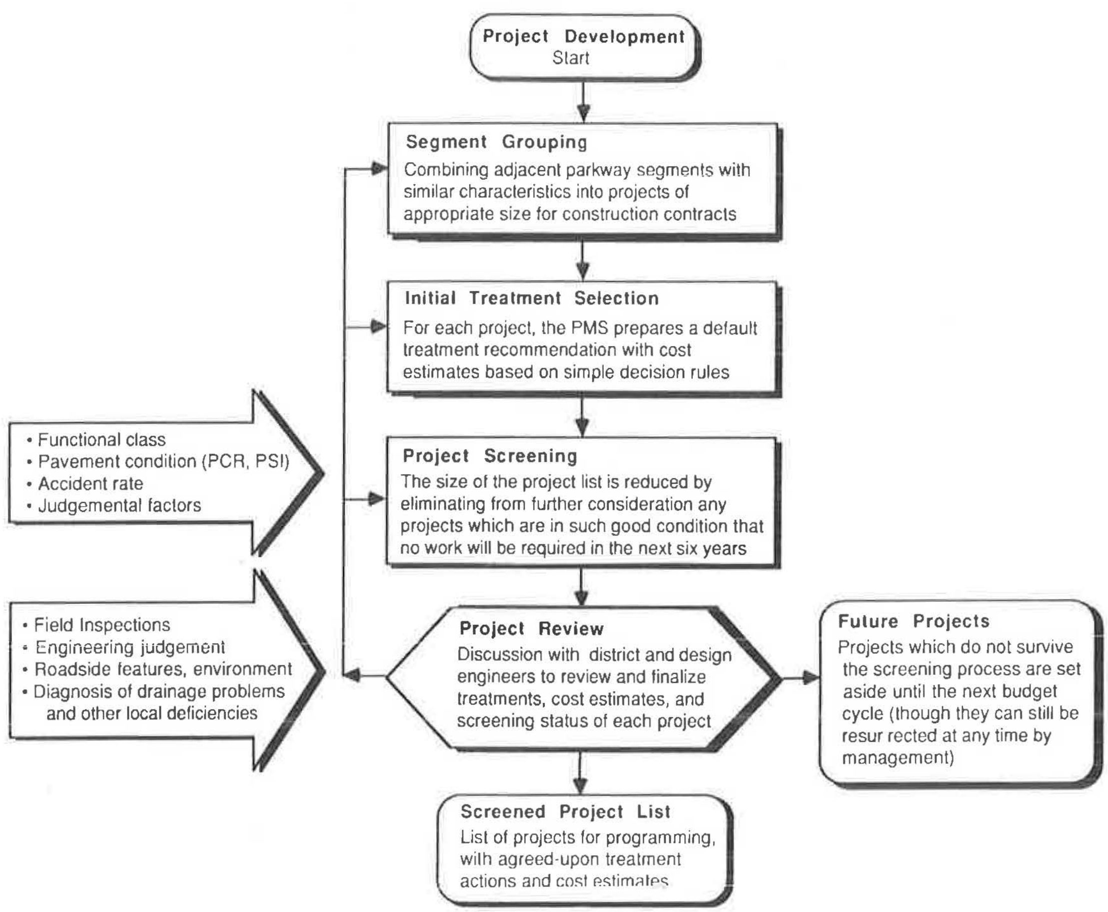

FIGURE 5 Project development.

that the MDC stays on course toward its long-range objectives, and sets aside enough resources to accomplish those objectives.

Figures 5 and 6 present the analysis framework used to prepare the 2- and 6-year capital programs. This framework is meant to be a flexible guide to the decision-making process, to keep it on track and to reduce the immense volume of data and objectives into specific final products. The data files and analytical capabilities of the computerized PMS have been designed to aid this process wherever possible.

The framework consists of two phases:

- Project development, where potential construction projects are defined and costs are estimated; and
- Program development, where priorities are set and implementation schedules are developed.

To some extent, the distinction between these two phases is blurred by the fact that, during the program development phase, it is still possible to modify the definitions of projects and their cost estimates. However, in the interest of keeping the process orderly and on schedule, it is desirable that as much of the project development phase as possible be completed before the program development phase begins.

Project Development

For data collection purposes, the 153-mi metropolitan parkway network is divided into 655 separate road segments, in order to faithfully reflect the true variation of parkway characteristics and conditions in the system. For the purpose of capital programming, however, these segments must first be aggregated into larger units suitable for construction contracts. The PMS supports this activity by producing reports that show adjacent parkway segments and the indicators of pavement condition and traffic that might be relevant for grouping segments together. A manual procedure makes the final decisions about segment grouping by assigning project identification numbers to each segment. The PMS then uses these segment-to-project assignments to build a project file, listing 150 to 200 candidate projects. It is this project file that is then used for all further program development activities.

For these candidate projects, the PMS computes initial default treatment recommendations and cost estimates, based on simple engineering decision rules. The recommendation comes in the form of a general strategy, with a typical cost per square yard for each strategy, as shown on the sample project review sheet in Figure 7. Because these decision rules take into account only the most common types of pavement deficiencies, it is possible for their recommendations to be off the mark in specific cases. However, the default recommendations are usually adequate as ballpark estimates, suitable for estimating overall funding needs and for suggesting strategies for particular projects in the absence of field inspections or more detailed analysis.

The program development phase can be simplified if the project list is reduced to the smallest size possible. There are many parkways that have recently been rehabilitated, or that are still in such good condition that they need not be given further consideration for the 6-year program. This list includes projects that are currently under construction, or those whose funding has already been allocated. The PMS includes a screening capability that makes it easy to exclude such projects from the process. This screening is conducted in two stages: an automatic stage that locates projects with high values of the pavement condition indicators; and a manual stage that allows manual adjustment of each project's screening status based on judgmental factors or knowledge outside of the database. With this procedure, the project list can be reduced to fewer than 50 projects—a convenient size for decision makers and legislators.

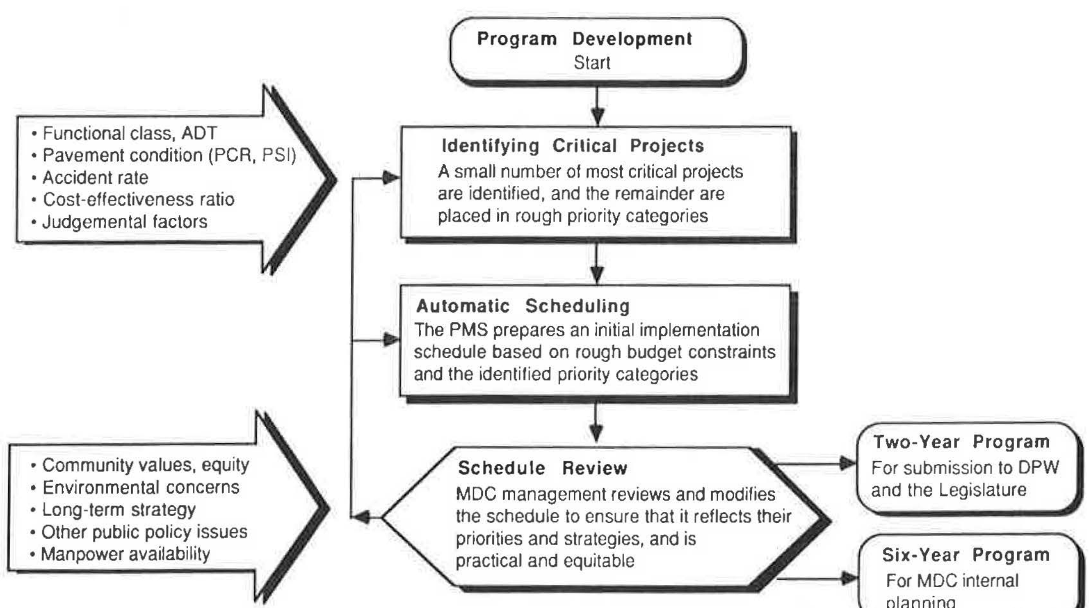

FIGURE 6 Program development.

METRO PARKS & ENGINEERING MANAGEMENT SYSTEM
Project Review Sheet 10-Dec-86

Project Number: 149 Contract Number: Project Name: BIRMINGHAM PY City/Town: BOS

GENERAL INFORMATION (office use only)

Pkwy Names/Endpts: BIRMINGHAM PY from ARSENAL ST BR to LINCOLN ST

MDC District: CH	Average Daily Traffic (ADT): 20593	Pavement Condition Rating (PCR):	45
Legislative Dist: 18S	Centerline Miles: 0.18	Present Serviceability Index (PSI):	2.4
Functional Class: 3	Lane Miles: 0.76	Fatal+Injury Accidents per 100M VMT:	90

TREATMENT AND COST INFORMATION Engineer's Initials: PMS Date of Recommendation: 08/15/86

Engineer's Treatment Recommendation: Type (A B C D E): B Description: Surface Replacement

Cost Estimate (unfunded):	Design:	0	Roadway Square Yards:	8471	Years Life Gained:	15
($000)	Construction:	119	Ramp Square Yards:	0	Est PCR Resulting:	100
			Adj Pkg Square Yards:	0	Cost-Eff Index:	0.577

COMMENTS Prepared by: PMS Date Last Updated: 08/15/86

516011: - SEVERE ALLIGATOR CRACKING @ CENTOLA ST, HIGH POTENTIAL FOR POT HOLE DEVELOPMENT - SUNKEN CB'S (PSI IS ESTIMATED) 516010: - DEPRESSED CB'S. INBOUND SIDE--DISTRICT ENGR REPORTS A HISTORY OF MANY DEEP POTHOLES TO SUBGRADE EACH WINTER--STRUCTURAL REPLACEMENT RECOMMENDED.

FIGURE 7 Example of a project review sheet.

The project development phase is primarily an engineering activity, though the participation of top management is important, specially during the screening procedure. Engineering judgment and flexibility are essential ingredients at every step. To ensure that the final list of candidate projects ready for prioritization and scheduling is acceptable to all concerned, a project review process is included as the key milestone signaling the end of the project development phase. In this process, project data sheets for all projects are prepared by the PMS, based on the analysis performed so far, and distributed to engineers in the central and district offices for their comments and corrections. These changes are then entered into the computer to produce the final screened project list.

Completion of the project review signals the beginning of the program development phase. With a compact, agreed-upon project list in place, what remains is to set priorities and schedules, and to prepare a persuasive 2-year bond authorization request for state the legislature.

Program Development

With the many objectives and many evaluation criteria that must be considered in order to produce a realistic capital program, it is difficult to order the potential projects into any strict priority sequence. What is needed is a process that is less mechanical and more judgmental, but that still produces decisions that can be justified by hard evidence. The data that have been gathered in the project file, along with the discussions that happen over the course of the 2-year period among management, engineers, and other agencies, provide the key information required to establish a program. The PMS helps to keep this process organized, and it analyzes and reports on the results; but it does not attempt to set priorities.

One straightforward way to attack an unstructured decision such as capital programming is to divide and conquer, and this is the approach supported by the PMS. Already, the project list has been divided by ruling out projects that have high condition indicators or that are already funded. Next, it is helpful to single out the projects that are clearly of highest priority. Management is already aware of many of the most critical projects. These may be projects about which many complaints have been received, or projects that are already partially funded. The PMS can produce a number of different types of reports that point out critical deficiencies. In particular, it can spotlight opportunities for preventive maintenance and relatively inexpensive overlay and surface replacement projects that represent opportunities to prevent the need for much more expensive reconstruction.

In the PMS, a provision is made for manually entering a project ranking to indicate rough priorities. These rankings can be based on engineering judgment or one or more of the technical criteria calculated by the PMS, such as pavement condition indices or accident rates. A ranking of 1 is assigned to the projects considered most urgent; a ranking of 2 is then assigned to the next-most-urgent projects, those that are approximately equal to one another in importance but of less urgency than Rank 1 projects. Similarly, successively lower-urgency groups of projects are given lower ranks. There is no particular constraint on the number of projects that fall into each rank category, or on the total number of rank categories. The ranking can be used, if desired, as a way of sorting projects in reports to show relative priorities. It can also be used as input to an automatic scheduling procedure provided by the PMS as a way to generate a first-cut implementation schedule.

All that remains to produce a final capital program is to make adjustments to the implementation schedule until management is satisfied with it, in a schedule review process. The PMS has capabilities to aid this evaluation. For instance, it can show projects grouped by treatment type to give an indication of the types of manpower that will be required each year, showing whether a steady program of preventive maintenance and rehabilitation has been included. It can also group projects by functional class or location (such as municipality or administrative district) to shed light on the equity implications of the program. By printing the project implementation schedule sorted by various pavement condition and traffic indicators, the PMS can show whether the priorities implicit in the schedule are consistent with actual conditions. Schedule changes in the PMS can be made as often as needed, and the reports reprinted. Considerable managerial judgment is required: the schedule may go through several iterations of review by MDC management and the MDC before it is finalized, and their comments may involve not only the rescheduling but also the downscoping and phasing of projects. All such changes can be readily accommodated by the system, whose reports then chronicle the convergence of the process onto a final capital program.

COSTS AND APPLICABILITY TO OTHER AGENCIES

Although the methodologies used in the PMS are general in nature, the specifics of the system are highly customized to MDC needs. Few highway agencies would require exactly the same data items as those listed for the PMS, for instance: most would want less information, but some might even require more. The choice of data items to collect and store in the system depends on the specific responsibilities of the organizational units that operate the PMS, as well as on the management priorities in effect at the time that the system is developed. In the MDC's case, for instance, a managerial concern for the setting of standards for roadside features such as curbing, sidewalk, and guard rail has led to the inclusion in the database of a comprehensive inventory of these features. The program development features are also customized to match the budgeting process and funding mechanisms unique to the MDC. Because the information needs of management change over time, the PMS must also be able to change. This flexibility is aided by the use of a commercial database manager as the backbone of the PMS, accompanied by thorough documentation of the system, so MDC information systems staff can modify data definitions and reports in the future.

Collection of such a large amount of information brings with it the cost of keeping the data up-to-date. At the MDC, a complete cycle of updating is expected to be completed every 2 years, at a cost of about 6 person-months per cycle. In addition, project engineers, at the completion of each construction project, are expected to update the road segments affected by the project as a part of the close-out procedure. Including the costs of analysis and report production and computer and software maintenance, the total cost of the new PMS is estimated to be the equivalent of one full-time staff professional. Compared with this ongoing cost of the PMS, the start-up costs of microcomputer implementation are quite small. A personal computer and database manager can be purchased for less than $5,000, and development of customized data files and reports, including complete documentation and training, require 3 to 12 person-months, depending on the complexity of the system. Of this startup cost, at least two-thirds is devoted to user-friendliness features such as menus and data-entry screens, documentation, and training. All of these costs are small compared with the amount of money to be saved by more effective decision making.

The IBM personal computer and 40-megabyte hard disk used in the MDC system offer more than adequate performance for this application. It is estimated that a road network six times the size of the 153-mi MDC network could be accommodated on the hard disk with adequate room left over for overhead requirements and other applications. For a system that large, however, it would be wise to use a faster computer, such as an IBM PC–AT or compatible, to keep running times reasonable. Still, for most PMS reports, printer speed is the limiting factor in system performance.

Inexpensive microcomputers and user-friendly database management software have changed the economics of software acquisition in many ways. It is now efficient and desirable to customize systems to fit an agency's unique needs, instead of relying on canned approaches to a problem. The ability to use standard personal computers and software in system design makes maintenance of the system less costly and more reliable. As a result, pavement management systems can be implemented in a more cost-effective way than ever before.

CONCLUSIONS

The programming procedures and analysis methodology developed and implemented for Boston's MDC have provided an effective tool for the agency to use in establishing pavement rehabilitation capital programs. Using microcomputer technology, it has been possible to improve MDC's access to hard, quantitative data for decision making without greatly increasing management's workload or sacrificing its flexibility. The design process for the computer system has proven that it is now possible and practical for small agencies with little previous computer experience to gain knowledge and confidence with computers while simultaneously participating actively in the design of a customized system. Based on this experience, it is clear that microcomputers offer great potential to improve the decision-making capability of smaller city and county highway agencies, who previously have not been able to fully exploit the data available to them.

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