ulate 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.

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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.

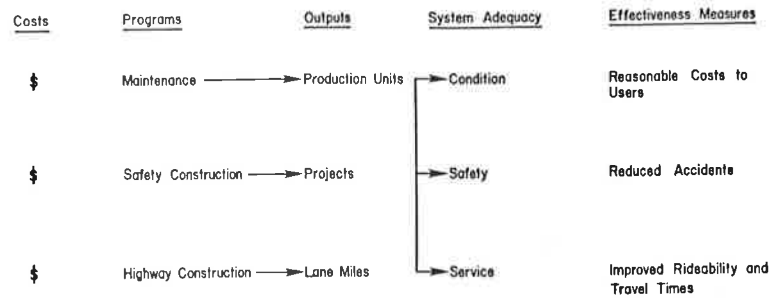
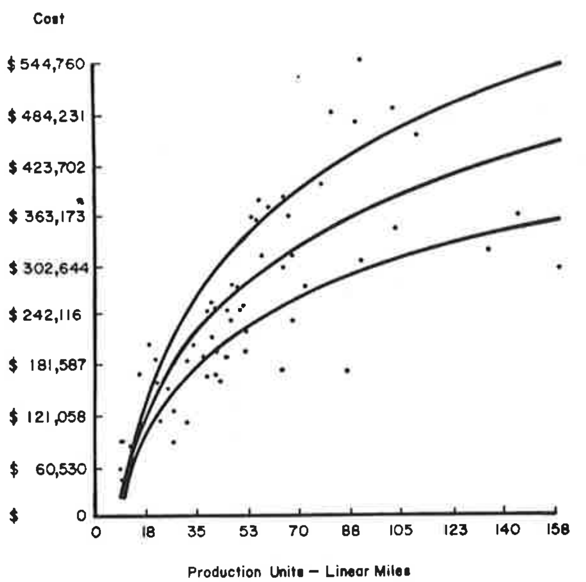


Figure 2. Surface treatment cost by production level.



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.

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