Highway Quality and Maintenance: Concepts and Quantification

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This paper presents concepts and considerations associated with defining highway quality and its implications, particularly for highway maintenance. Factors that affect highway quality are reviewed, and the roles and needs of various organizational elements are discussed. These elements, which range from national and statewide policy decisions to maintenance activities in the field, emphasize the need for a consistent scale of quality assessment and presentation techniques relevant to highway user impacts, financial and economic policy decisions, program scheduling and management, and maintenance activity monitoring. Definitions of micro- and macro-quality and their impacts are addressed, and quantitative relationships between new, threshold, and critical quality levels are illustrated and related to maintenance impacts in order to provide a context and framework for establishing maintenance workload, performance, budget, and cost models. Key issues in highway quality related to maintenance impacts are explored, and initial descriptions of maintenance impacts are related to threshold and critical quality levels to assist in developing an integrated approach to user cost and impact analysis.

Deterioration of the national highway system has generated technical and general (1, 2) concern for some time. A recent review (3) of highway maintenance expenditures describes rapid deterioration of facilities caused by inadequate maintenance funding. This indicates a need for better quantifying and presenting factual and readily understandable indicators of cost, travel comfort, and related impacts to policymakers and the public.

Highway quality, how it is measured, who interprets and acts on the information, and how the implications for users and nonusers can be expressed and presented most effectively are subjects for which guidelines are at present being developed. Two examples of current efforts are a project concerning maintenance level-of-service guidelines (4) and a project developing relationships between highway damage components and maintenance costs (5).

The concepts presented here describe potential methods of quantifying highway quality relationships to assist those concerned with maintenance in better responding to emerging needs. They also describe some key relations between user impacts and highway quality as a basis for further analysis.

Concepts of micro- and macro-quality described in this paper are extensions of work done in development of the Massachusetts maintenance management system. The user impact concepts described here that relate to micro- and macro-quality were developed separately.

POLICY AND FUNCTIONAL DETERMINANTS OF HIGHWAY QUALITY

A brief overview of the context in which highway quality exists and its relation to factors affecting it—quality determinants—are summarized in Table 1.

The standard management response to deterioration of highway quality is to attempt to satisfy the need for maintenance through a logical process of actions determined by specific decisions. A series of steps leading from an objective, quantitative estimate of existing highway quality through the budgeting and resource-allocation process is shown in Figure 1. This process and its components provide a guide for isolating and considering highway quality, maintenance, and resulting impacts.

The state of the art in highway maintenance needs a generally acceptable definition of highway quality to provide a basis for improved decision making. An approach to defining needs, agency roles, and quantification of quality and maintenance programs is described in the following sections.

ORGANIZATIONAL ROLES AND ASSOCIATED QUALITY DEFINITIONS

The term "highway quality" undoubtedly has different meanings for different individuals. For example, a pavement maintenance foreman will view a certain segment of highway as needing specific repairs based on his or her evaluation of how severe the cracking, rutting, or other deterioration may be. Policymakers at national, state, or municipal levels, however, must take a wider view and balance the quality of a segment of a system (and a user's reaction to it) against that of other segments and, ultimately, the need for funds in competing sectors of the economy such as housing and education.

Because the budget and policy issues affecting legislative decisions are basically influenced by the actual level of maintenance, and vice versa, it is desirable that methods of measuring and quantifying highway quality be consistent. Each organizational element, however, will be faced with decisions, variables, and data-presentation needs unique to its role, as summarized in Table 2.

Furthermore, maintenance of a highway network must be responsive to user opinions about how well the system satisfies perceived needs. An information flow process for a typical state highway system is shown in Figure 2. To enable an adequate response by legislative officials to user perceptions of quality, a generally understood and recognized method of quality measurement and its maintenance implications is essential. Policymakers must be informed of the effects of their maintenance funding decisions in a readily understood manner.

With the foregoing considerations in mind, one finds that an adequate and consistent definition of highway quality should

1. Be based on measurements needed to describe the condition of highway components from a detailed engineering and technical viewpoint to assist engineers and maintenance and management personnel;
2. Have a structure that assists in formulating direct relations with construction and maintenance performance standards;
3. Be consistent with potential national and international standards to assist in establishing uniform measurement and quality-assessment procedures and methods of comparison; and
4. Be readily adaptable to displaying broad areas of impacts resulting from specific budgeting strategies to policymakers.

Table 1. Highway quality organization, maintenance roles, decision variables, and information needs.

Highway Quality Determinants	Effects on Highway Quality and Maintenance Needs
Policy and financing	
Capital- or non-capital-intensive investment strategy based on available program funding, sector apportionments, and economic assistance policies	Determination of maintenance extent and frequency
Facility characteristics	
Geometrics such as grade, cross slope, curvature, and placement of appurtenances	Effects of surface drainage and vehicle climbing, braking, and accident characteristics on facility condition
Pavement, structural, and dimensional specifications	Service capability and rate of deterioration
Appurtenance design and specifications such as drainage structures, light standards, and energy attenuators	Efficiency in ensuring protection of facility from environmental conditions and users
Materials specifications such as those for aggregate, concrete, paint, and bitumen	Service capability and rates of deterioration
Environmental conditions	
Subsurface condition such as ground water, soil, and geological conditions	Subsurface and bearing capability of pavement and rate of facility deterioration
Climatic conditions such as rainfall, snowfall, temperature (levels and variations), and freeze-thaw cycles	Amount of moisture and number of freezing cycles and related deteriorating agents
Regional conditions such as potential floods, rock falls, wind-borne deposits, storms, and other natural hazards	Frequent need for emergency maintenance work often the cause of general deterioration
Human environment	Debris
Traffic and use conditions	
Traffic volumes such as annual daily traffic and seasonal and daily variations	General traffic use indicator
Vehicle mix such as percentage of trucks and buses	Characteristics of loading, particularly heavy trucks and other special conditions, affecting pavement deterioration
Vehicle loading (axle loads)	
User characteristics (trip purposes)	Special highway needs such as provision of rest areas and special seasonal or weekend traffic activities
Accidents	Need for clearing traveled way of accident debris
Prior maintenance	
Expenditure levels	Limts on the extent of resources expended on maintenance resources
Field operational efficiency	Productivity and efficiency of resource use
Maintenance management effectiveness	Setting priorities, responding to defined needs, monitoring performance, assisting field operations, and informing public and policy-making bodies

HIGHWAY QUALITY CONCEPTS

If one ignores the effects or impacts of the quality on the users or environment, physical highway quality can be defined as the state of a particular highway element or group of elements existing within the facility itself at any point in time. However, to define more precisely what is meant by highway quality and how it can be measured, it is useful to explore in greater detail the concepts of micro- and macro-quality and how they can assist in providing meaningful functional relationships.

Essentially, micro-quality can be described as the condition of a specific small segment of the highway, such as a limited area of pavement or the amount of loss of cross-sectional area of a structural member in a bridge. Macro-quality, on the other hand, would pertain to the extent that the micro-quality exists throughout the system. It could be stated, for instance, that 40 percent of the pavement in the system had significant cracking damage and that 5 percent of the bridges had one or more structural members with a significant loss of cross section.

Table 3 lists some examples of micro- and macro-quality descriptions for typical maintenance items. Further characteristics of this approach are described in the sections that follow.

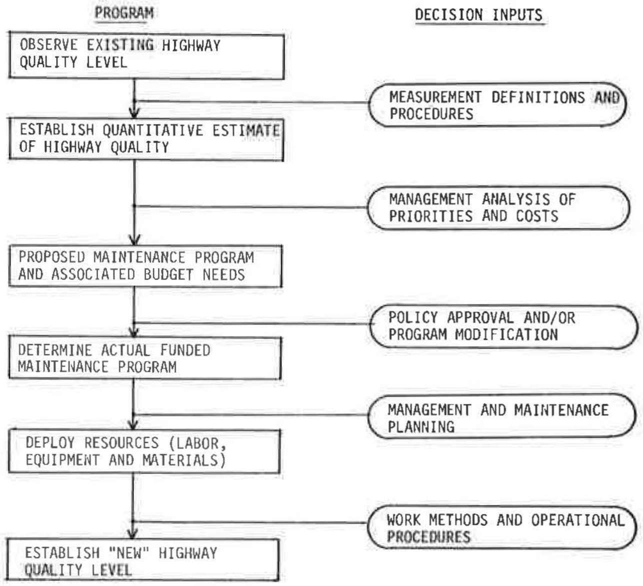
Micro-Quality

Micro-quality of each element of a new facility is initially set by the design specifications for each element. For example, surface roughness can be specified in terms of present serviceability index (PSI), and drainage flow is determined by the capacity of the drainage pipe or culvert. Over time, the micro-quality of each element will deteriorate to a different extent according to variations in use and environmental conditions.

Micro-quality is directly related to the functional and operational effectiveness of an element. It is the micro-quality that directly affects user safety, comfort, and convenience and indicates whether remedial steps should be taken to preserve the initial investment.

Uniform micro-quality will normally exist at any

Figure 1. Maintenance program and decision impacts.



point in time over those portions of an element where design, construction, specification, traffic, environmental factors, and age are also uniform. Other portions of the same element that are subjected to different use and environmental conditions will deteriorate at different rates. Hence, at any time following original implementation, the total inventory of any element will consist of a number of portions at different micro-quality levels—a distribution of micro-quality levels.

Deterioration of the micro-quality of a highway element over time can be illustrated graphically: Figure 3 shows the micro-quality deterioration curve of an element with respect to three important levels.

The first level is the new, or as-built quality q_N, which is generally the quality level at which an element should ideally be maintained, although in practice this is often not fully achieved. Second is a threshold quality, q_T, at which point it is desirable (as established by policy) to commence maintenance operations. This quality level can be established (a) by means of engineering judgment concerning the extent to which an element of the highway system should be allowed to deteriorate (usually considerations of preservation of investment and user safety are key determinants in this decision); (b) by means of mathematical techniques that consider

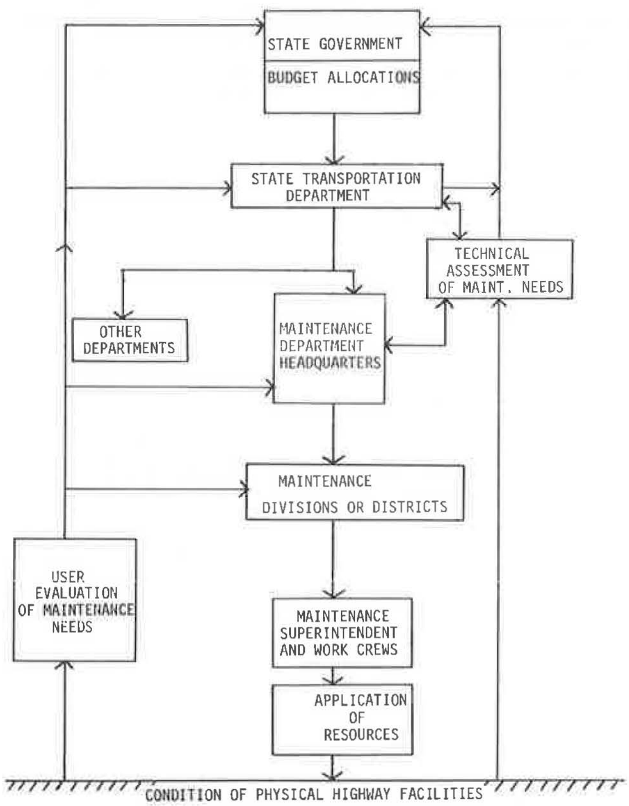
Table 2. Organizational roles, highway quality, and maintenance information needs.

Organizational Element	Maintenance Role	Decision Variables	Data Needs and Presentation Formats
National, state, and local government and legislature	Funding allocations to reflect competition between sectors for funds, general transportation priorities, and highway, regional, classification, and other financial programs	Funding available Public acceptance of highway conditions regarding safety, convenience, economical transport, and uniform highway quality Geographical apportionment Trade-offs between capital and non-capital expenditures National, regional, and local policies and priorities	Definition of highway quality or condition to readily reflect changes in available funding Annual comparison of highway quality for key items such as pavement and bridges Annual expenditures associated with quality levels Data summarized and condensed to show principal features needed, with detailed background information available if needed, impacts of program on users and general public clearly stated
Transportation agency administration	Similar to above but with greater weight given to needs based on technical performance standards	Similar to above but also including technical and administrative determinants of program effectiveness and costs and implementation within specific jurisdictions	Similar to above but generally in greater detail
Maintenance management headquarters	Administration and allocation of resources within maintenance jurisdiction	Policy guidelines for highway quality Available funds and resources New methods and procedures Evaluation of performance and effectiveness Response to district needs and coordination between jurisdiction or other districts Budget apportionments	Management information for monitoring performance and maximizing maintenance effectiveness with regard to quality versus funding; budget computation analysis and evaluation
Maintenance district or section management	Similar to headquarters but with primarily district or section emphasis	Similar to headquarters but primarily with district or section emphasis including detailed priority and work schedule requirements	Similar to headquarters but primarily with district or section emphasis related to specific maintenance activities and labor, equipment, and materials use
Local, state, national, and international technical, research, and professional organizations	Organizations playing an advisory role in defining and substantiating uniformly applicable approaches to highway quality, measurement, analysis, and evaluation	Methodologies and approaches for establishing and defining highway quality; relating quality to funding, maintenance procedures, user needs, local, regional, and national maintenance policies and standards; and recognizing essential differences due to geographical, economic, cultural, and government characteristics	Consistent terminology and recognition of principal features of technical, economic, and management tools to assist comparison of key performance indicators

capital, maintenance, and user costs together with facility specification variables to determine a quality level that offers the least cost; and (c) by imposing a threshold level on the element because of a lack of adequate funding or other resources required to carry out the necessary maintenance. In this last, uncontrolled situation there is considerable danger of the threshold quality's falling below the critical level. The third level is fiscal policy measures that include the above approaches to a greater or lesser degree. A critical quality, q_c, exists when the element becomes unserviceable in terms of its function as a highway component. Examples of highway segments in this category are those where

1. Posted reductions in speed are required,
2. Detours are required,
3. Significant accident hazard exists,

Figure 2. State highway department information flow.



4. Lane or lanes are fully or partially closed,
5. Vehicle weight must be reduced,
6. Imminent or unpredictable structural failure is likely,
7. Undue costs accrue to the direct users and the general public, and
8. Any situation exists where the agency concerned could be considered not to have provided adequate professional diligence, judgment, and care in protecting the public from injury, if a substandard condition is allowed to persist.

Macro-Quality

Macro-quality of an element can be described as the extent to and the manner in which micro-quality is distributed throughout the inventory of that element. Because of this, macro-quality, Q, can be expressed in several ways that can assist the analysis of highway quality. These include (a) a frequency distribution of the micro-quality levels with the element, (b) average and median values and appropriate measures of dispersion, and (c) the proportion of the element that exists above or below some specified quality level (such as specified threshold levels).

Figure 3. Micro-quality concepts.

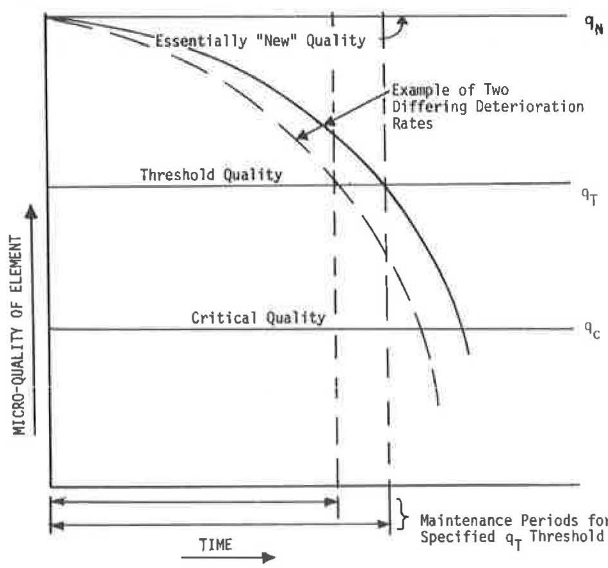


Table 3. Examples of micro- and macro-quality.

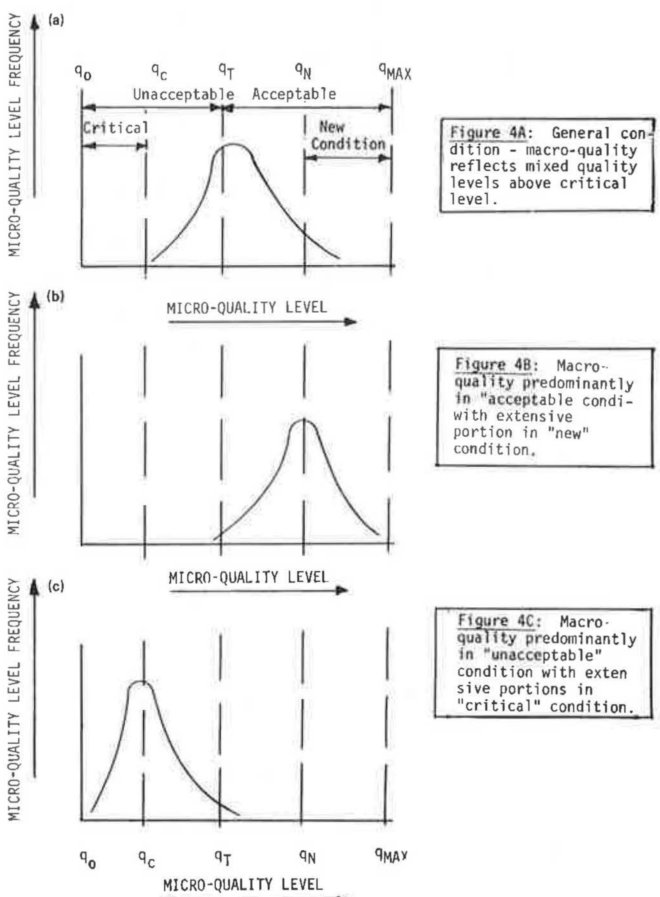
Maintenance Item	Micro-Quality Measurement	Macro-Quality Measurement
Pavement surface	PSI*, alternatives: roughess or failure severity	Area of pavement existing at or below a given PSI or PSI threshold
Guardrail	Measure of distortion or misalignment of individual segments	Length of misaligned segments
Drainage ditches	Depth of standing water or other obstructions	Length of drainage for water deeper than a given standing-water or obstruction depth
Roadside grass	Height of grass	Area of grass taller than a given height
Bridges	Cross-sectional area of critical structural members and other criteria of structural adequacy	Number of system bridges or possibly number of spans having deficient structural members

*PSI is present serviceability index.

Generally, if the micro-quality of a specific element is normally distributed (other distributions are also possible), the various terms and relations can be illustrated as shown in Figure 4.

In Figure 4a the area under the curve lies between zero quality, q_0, and q_{MAX}; there is 100 percent of the inventory of the element; the acceptable proportion of the inventory of the element is that shown under the curve between the micro-quality levels q_T and q_{MAX} (this is the proportion of the inventory above the micro-quality threshold level q_T); and the unacceptable proportion of the inventory of the element is that shown under the curve between q_0 and q_T. This is divided into two segments: the portion that is critical (q_0 to q_C) and the proportion that requires maintenance but has not yet reached a critical stage (q_C to q_T).

Figure 4. Comparison of micro- and macro-quality.



Figures 4b and 4c illustrate hypothetical cases of new and extensively deteriorated highway elements, respectively. In the latter case a significant portion of the element lies within the critical zone (q_0 to q_C). Also, if the threshold quality lies significantly below the critical value ($q_T \leq q_C$), then the entire inventory of the element in question may need immediate attention.

Micro- and macro-quality can be related to pavement performance by considering, for instance, that the micro-quality distribution for "premium" pavement would lie to the right of the distributions for pavements with normal design standards, other conditions being equal.

For any highway element, the numerical value of macro-quality will increase as the value of the threshold quality (a micro-quality) decreases. In quality-control terminology, the lower the quality acceptance level, the greater the acceptable quantity.

In practice, macro-quality can be expressed in terms of the deterioration and remedial work required in terms of work units (area or volume, for instance) of each inventory item to bring the item to as nearly new a condition as is reasonably possible. The quality of the sample segment can thus be expressed as a direct function of the extent of the maintenance or repairs needed.

For example, if there are 1000 linear meters of guardrail in a segment (U_s) and, based on the assessment observations, 100 linear meters of it is found to be in need of repair (U_D), the quality index (Q_I) for that item within the sample segment is

$$Q_I = (1 - U_D/U_s) \times 100 = (1 - 100/1000) \times 100 = 90 \text{ percent} \quad (1)$$

Thus, direct measurement of deficiencies and of the total inventory of each element provides a direct assessment of the highway quality expressed as a proportion of each element's inventory. This method of express-

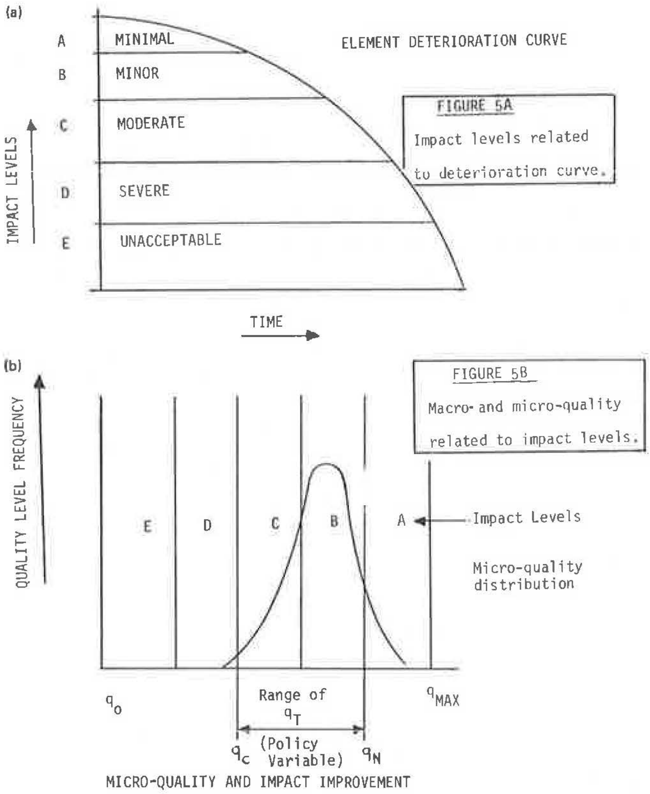
Table 4. Initial listing of maintenance impacts.

Level	Rating	Highway Condition	User Impacts
A	Minimum	Ranges from new condition to minor deviation from design and operational specifications	Highest level of service attainable in terms of safety, riding comfort, aesthetics, and operational effectiveness
B	Minor	Ranges from minor deviation from specified design conditions to occasional and isolated instances where deterioration is apparent but does not need immediate attention	Occasional instances of reductions in riding comfort, operational effectiveness, and aesthetics; no deterioration in safety aspects
C	Moderate	Ranges from isolated instances of deterioration to locations where maintenance should be performed within 12-month period to avoid adverse significant user impacts or loss in investment	Significant perception of deterioration in aesthetics and some perception of reduced riding comfort and operational effectiveness
D	Severe	Ranges from locations where deterioration is noticeable in a significant number of elements, generally most severe in roadside elements but also in traveled way	Significant perception of deterioration in riding comfort and operational deterioration such as need for reduced speed; perceptible accident potential exists
E	Unacceptable	Physical quality ranges from a significant number of locations needing scheduled maintenance to locations where deterioration requires emergency repair or closure of the facility to the public for safety reasons	Accident potential and riding comfort induce extensive loss of operational efficiency due to lane closures, surface deficiencies, debris, or other obstruction in right-of-way

ing quality assists direct comparison of deterioration, remedial work needed in terms of work units, and the Q_I, which permits direct numerical comparisons of highway quality between various jurisdictions and in different time periods.

Furthermore, the assessment of the macro-quality of each element provides a direct numerical value of the maintenance work to be done in terms of work units. When multiplied by appropriate performance standards and equipment and materials costs, the quality assessments thus provide an initial cost estimate, based upon the highway's condition, for objective budget estimates and maintenance planning.

Figure 5. Highway quality and user impacts.



USER IMPACTS

Closely related to highway quality and maintenance is the concept of user impacts. Deteriorated pavements and other conditions cause physical damage to vehicles, increase accident probability, and induce less than optimum route choice. In turn, these factors can lead to many undesirable situations ranging from loss of productivity to excess energy consumption and associated costs.

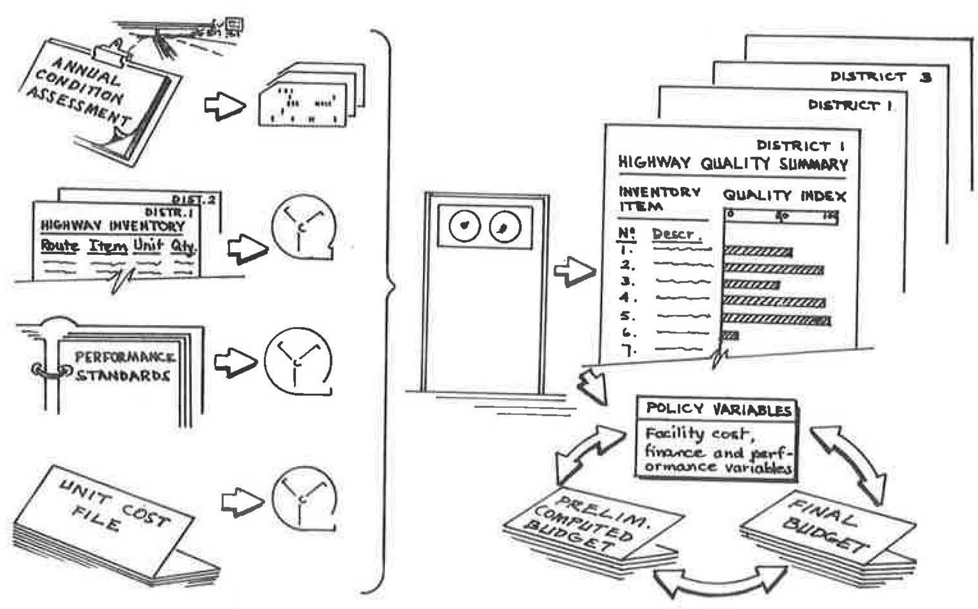
An initial attempt at delineating qualitative descriptions of maintenance impacts is shown in Table 4. This describes a scale of impacts from A through E, ranging from the impacts associated with a recently constructed and properly maintained road (level A) to those where extensive operational deficiencies and significant potential for accidents exist (level E).

Some of the key relations between micro- and macro-quality and maintenance impacts are shown in Figures 5a and 5b. These diagrams illustrate conceptually how the numerical values that could be assigned to different qualities resulting from specific maintenance policies are likely to affect highway users. This also provides a basis for formulating expressions describing total costs.

In Figure 5a, the relation between micro-quality and the various impact levels is shown. Level A is shown to occur above q_N, while, at the other extreme, level E is shown below the critical quality level, q_C. The threshold quality, q_T, a variable depending on specific policy decisions, can occur throughout the range of impact levels. From the point of view of preservation of investment and user comfort and convenience, it will usually be preferable to set q_T somewhere within the range of maintenance impact level C, described here as a moderate impact. Deferred maintenance policies may set $q_T \leq q_C$ within impact levels D or E (severe or unacceptable, respectively).

Figure 5b shows how the quality and impact levels as well as the macro-quality of the highway can be related. The threshold level, q_T, is shown at the same impact level as in Figure 5a. For the distribution of quality throughout the system, the area under the curve

Figure 6. Highway quality assessment and budgeting process.



for each impact level indicates the proportion of the inventory that exists at that level. Thus, the amount of quality deterioration and the consequent maintenance effort required to bring the total inventory of each element up to an acceptable level can be determined.

MAINTENANCE, BUDGETING, AND POLICY DECISIONS

The concepts presented here have been aimed at providing a structure, with appropriate definitions and hypothesized relationships, within which highway quality, maintenance, and user impacts can be quantified. Although not identical to this approach, particularly in the concepts of micro- and macro-quality and user impacts, several maintenance management systems have been implemented that feature a formal highway quality assessment procedure to provide a basis for both future budgeting and maintenance action and for preparation of numerical and graphic descriptions of the highway quality.

For instance, the Ohio Department of Transportation has used an assessment process for some years (6, 7) that relies on a system of recordable conditions measured in units that can be associated with the extent of maintenance needed and, subsequently, to a district and statewide annual maintenance budget.

A quality-assessment procedure now being investigated for the maintenance management system of the Massachusetts Department of Public Works is based on the quality index described earlier. In this system the threshold quality level is described in appropriate micro-quality terms that can be directly related to specific maintenance activities (8). A further development in Massachusetts is the introduction of work load and cost models responsive to many of the variables, including design, and traffic and environmental factors (9) mentioned earlier.

The Ohio approach measures or identifies samples of the micro-quality condition of selected elements and compares the proportion of their occurrence between maintenance jurisdictions and over time. It is not directly linked to the work load but provides an indicator of highway condition as a guide for budgeting. In the Massachusetts system the proposed measurement of quality would estimate specific amounts of deterioration of the element related to the total inventory. The mechanism for converting this to a proposed budget is still under consideration.

In general, as portrayed in Figure 6, an annual quality assessment, when combined with the highway inventory, performance standard, and unit cost files, can produce a highway quality summary for each district. The information can also be used to compute first a preliminary budget and, through a series of iterations and modifications, a final budget that is responsive to policy for funding allocations and desired level of highway quality.

Probably the greatest potential advantage of the micro- and macro-quality concepts is that the quality index, or a similar measure, indicates how much inventory is deficient and, therefore, the amount to be budgeted to ensure the required standard. For example, if the quality index for guardrail in a district is 0.91 (or 91 percent of the inventory is of acceptable quality) for a given year, based upon measurement or estimates, and if a satisfactory index is 0.99 (as determined by policy), the required budget to achieve the policy objectives for this element will be

$$[Q_I\text{ (policy)} - Q_I\text{ (existing)}] \times \text{inventory extent} \times \text{maintenance cost per unit} \quad (2)$$

or

$$[0.99 - 0.91] \times \text{inventory extent} \times \text{maintenance cost per unit} \quad (3)$$

CONCLUSIONS AND NOTES ON FURTHER RESEARCH

In presenting the issues and concepts here, I have attempted to add to current knowledge about the need for and quantification of highway quality. Some of the key elements of current concerns have been placed in an analysis format in order to better define a quantitative approach consistent with the needs and roles of a wide range of people and organizations, including highway maintenance departments, policymaking and decision-making agencies, and highway users in general.

Future research directions that could be beneficial to the technical and administrative aspects of developing acceptable maintenance management procedures include

1. Investigation of consistent or standardized information formats for various organizational elements concerned with maintenance (in particular, the preferred means of presenting information and cost implications in a meaningful way to policymakers to assist in the funding and budgeting process);
2. Continued acquisition and analysis of data to adequately quantify micro- and macro-quality relations and the means by which these, or other concepts, can assist in the maintenance process; and
3. A continuing analysis of maintenance impacts to ensure that the varied effects of specific policies on different classes of road users, and on the general public, can be adequately documented.

In particular, highway quality assessment techniques and further exploration of the quality and impact relations indicated in Figures 3, 4, and 5 should prove advantageous from the point of view of defining numerical relations for computational and presentation purposes. Recent implementation of maintenance management systems by many organizations will significantly assist this effort.

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**J.G. Schoon was with Byrd, Tallamy, McDonald and Lewis when the concepts of micro- and macro-quality were being developed.*

A Systems Approach to Maintenance Station Location

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The California Department of Transportation (Caltrans) has developed a procedure for identifying appropriate locations for facilities needed to support the highway maintenance mission. The traditional approach has failed to answer the questions of whether the facility is really necessary and is in the best location, whether the adjoining stations are affected, and what the fiscal impacts of possible alternate locations are. The procedure developed by Caltrans considers the trade-offs between capital costs and operating costs over the project's life and emphasizes changes in expected travel costs as a function of maintenance station location. These costs can then be weighed against the social and administrative aspects of deciding what facilities are needed and where to build them. Computerized network simulation is used to estimate travel-time impacts, while capital costs are evaluated by using discounted cash flows. A field application of the procedure, as a portion of the siting-decision process for a new facility, Beckwourth, is discussed, along with results observed after a year's application.

Twenty-five percent of California's 325 maintenance stations are older than 30 years; almost 20 percent of its stations are 40 years old or older. Although age alone does not determine the obsolescence of a facility, it is a major consideration. The aggregate age of California's facilities gives a partial insight into the magnitude of the problem that the California Department of Transportation (Caltrans) must face. The present dollar cost of modernizing the system could easily approach $100 million. This total grows daily as more stations join the ranks of the obsolete and as inflation continues its upward march.

Historically Caltrans' practice has been to identify specific deficiencies in maintenance stations and to address these specifically through a project. Most commonly the correction proposed is either reconstruction of the facility or construction of a new one nearby. The notable exception has been in the larger metropolitan areas, where the emerging trend is to develop centrally located service centers.

Appreciating the magnitude of the problem, Caltrans' management took a second look at the task. Over the past 30-40 years the highway system has evolved and changed considerably from the system that the maintenance stations originally served. From this second look it became apparent that the older facilities are no longer in the best locations to effectively support the maintenance mission.

In early 1976 the California Highway Commission challenged a project to locate a new facility in the remote community of Covelo in northwestern California. Responding to this challenge required a comparison of the total system cost of supporting the highway from the proposed local operating base in the Covelo area against the cost of supporting the highway from the next proximate bases at Willits or Leggett.

It was necessary to estimate the total costs for the various siting decisions. The maintenance-facilities siting model, developed to satisfy this objective, contains two major elements: the operating cost element and the capital cost element. Changes in the costs of maintenance operations as they relate to the location of the maintenance stations are examined in the operating cost element. The impact of capital expenditures, both present and future, are considered in the capital cost element. The facility siting model brings these elements together in a format that permits management to make the critical trade-off (see Figure 1).

The method of analysis that was developed to meet this purpose is the topic of this paper.

MAINTENANCE OPERATING COST ELEMENT

This element is used to simulate the normal highway maintenance function. The work done in each highway section is studied and the existing crew travel patterns analyzed. From the information gained, we can estimate what our costs might be if we were to relocate.

By working with reasonably short, fairly uniform stretches of highway linked together into a network, the actual road system may be simulated. If the time consumed by crew travel, their travel speed, and the travel distances are known, then an estimate of travel frequency can be made. In turn, these calculated travel frequencies can be used to estimate the total travel time needed by crews to come from a new location.

Terms

Throughout the discussion of the operating cost element, certain terms are used repeatedly. These terms are defined as follows: