INCORPORATING QUALITY STANDARDS AND IMPACTS WITHIN HIGHWAY MAINTENANCE MANAGEMENT

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Assessments of future maintenance needs, levels of effort, and costs have traditionally been expressed through predictions of maintenance supply (generally in units like dollars or manhours per lane mile). Although this approach is adequate for many management needs, it does not enable one to explore systematically the effects of changes in maintenance policy on future costs and road performance. However, the increasingly important strategic role to be played by maintenance and rehabilitation, and higher costs of providing maintenance services, have recently focused attention on better management practices to define maintenance demands, establish priorities among maintenance activities, and relate alternative policies to future impacts on road service. This paper describes the development of demand-responsive concepts for maintenance planning and policy formulation, based upon work conducted in separate projects for the Commonwealth of Massachusetts and the Federal Highway Administraiton. Analytical components of the demand-responsive approach include (1) numerical measures of maintenance levels of service, or quality standards; (2) quantitative model to predict the condition or deterioration of specific road features as a function of the relevant physical, environmental and traffic factors; and (3) quantitative models to assess the impacts of maintenance performance, as for example in the areas of preservation of investment, user consequences, and accident prediction.

Historical Perspective

Maintenance programs at the state level historically have been subject to several simultaneous constraints -- budget limitations imposed by the executive or legislative branch, labor and equipment restrictions, seasonal limitations on certain work activities, inability to shift work from emergency to preventive maintenance, and methods of budgeting and appropriation based upon line-item or accounting categories (rather than upon program priorities), to name a few. These constraints have influenced not only the past thinking of maintenance managers, but also the fundamental structure and approach of the maintenance management systems that have evolved over the past fifteen years.

The objectives of the systems developed by individual states were to help plan, budget and manage highway maintenance. To overcome the management weaknesses of the line-item or accounting budget, principles of performance budgeting were introduced. Performance budgets organized planning and control around specific maintenance tasks, permitting a more comprehensive and objective review of the distributions of costs by activity, location, or cost element, and fostering comparisons of projected expenditures versus maintenance program objectives. The planning and scheduling components of these systems enabled managers to allocate scarce resources over a year, and to strike a better balance between maintenance priorities and seasonal resource constraints. A work monitoring subsystem, coupled with proper field reporting procedures, provided comparisons between actual and predicted costs, work performance, productivity, and resource consumption, pinpointing maintenance jurisdictions or activities requiring closer attention.

Furthermore, as part of the performance budgeting approach, maintenance models were developed to predict future labor, equipment and materials costs by activity. The approach taken within these models typically involved either (1) regression relationships between annual maintenance costs (or manhours) per unit of road and relevant physical or operating variables (width, pavement type and thickness, average daily traffic, environmental parameters, etc.); or (2) average workload rates, called quantity standards, observed in past maintenance operations and expressed in terms of annual measures of work per unit of road (e.g. for pavement patching, number of tons of material placed per lane mile). The former allowed some variation by location or in year-to-year predictions to account, say for increases in traffic volume or changes in road characteristics; the latter represented essentially statewide averages of maintenance activity performance, and were thus static over different types of roads and over time.

Although the various state systems in use today differ in their scope and level of detail, in general they are characterized by the fact that, in predicting future maintenance requirements, their primary focus is on the **ability to supply maintenance services**. In other words, the predictive models employed estimate the labor,

equipment, material, or dollar resources needed to produce some level of maintenance effort, but not the factors that caused the maintenance requirement in the first place. Although this approach is open to criticism, it is understandable in light of the organizational and administrative realities surrounding maintenance program development which were true in the past, and persist to some extent to this day.

There were some key advantages to structuring early maintenance models based upon predictions of supply. First, they were a simple and direct means of estimating future budget requirements using an objective analytic approach. Second, they could implicitly account for special local conditions that would affect the aggregate amount of maintenance required (e.g. types of subgrade soil; local climatic conditions; quality of pavement construction; and so forth), and that might otherwise be difficult to represent explicitly.

Perhaps most importantly, however, these supply-oriented models satisfied local management needs. The institution of performance budgeting measures placed budget development on a more rational basis, but it could not eliminate constraints on the maintenance effort imposed by budget ceilings, labor and equipment limitations, and the like. Rather than concerning themselves with the moot issue of actual maintenance demand, therefore, managers directed themselves instead to the pragmatic question of how to accomplish maintenance more efficiently under a fixed level of resources. Performance budgeting concepts, assisted by models based upon maintenance supply, were adequate for this task.

Demand-Responsive Concepts

Motivation

Several trends through the 1970s have advanced maintenance management needs beyond work monitoring, budget prediction and cost control, to broader issues of maintenance policy planning. First, the national highway investment has grown by at least $200 billion in 1979 dollars (1), due largely to near completion of the Interstate program. Many of these highways are approaching ages of 15-20 years; maintenance responsibilities, and the need to estimate and allocate available resources effectively, will increase accordingly. Second, significant changes in the funding of highway maintenance and rehabilitation appear forthcoming, as evidenced by declines in user tax collections and initial Federal involvement through the 3-R program; procedures to allocate available funds, and to assess the impacts of maintenance deferred or foregone, will likely be required. Third, several independent developments -- such as heavier allowable vehicle loads, the advent of new maintenance technologies, and stricter legal interpretations of highway maintenance liability -- collectively imply changes in maintenance needs and methods of performance over time. The tendency is growing to counter arbitrary annual budget restrictions with better information on what impacts the provision or rejection of additional maintenance dollars will cause.

Planning Requirements. Managing this changing maintenance program and developing the capability to assign priorities among ever-increasing maintenance demands requires information and analytic methods to properly assess competing needs, and to evaluate costs and impacts of different policies on a national scale. Moreover, to be comprehensive such management approaches must recognize highway maintenance within a broader context of transportation planning and administration, and to view maintenance policy formulation at several levels.

Strategic. First, at a very broad level are strategic decisions concerning use of maintenance versus capital investment to provide a designated level of road performance. The most prevalent examples of these types of decisions are in pavement design, where a close interaction exists between initial design quality and future maintenance needs. Taken to its extreme for very high-volume roads, this type of decision leads to the design of premium or "zero maintenance" pavements involving significant capital investment but eliminating any practical need for maintenance. However, similar investment-maintenance tradeoffs can be cited regarding pavement maintenance versus programs of periodic reconstruction or strengthening; the need for periodic bridge painting versus use of self-oxidizing steels; and construction of paved waterways versus cleaning and shaping of natural ditches, to name a few. In each case the choice of which policy to follow will depend not only on the cost differential between respective alternatives but also on the relative capacity to provide adequate levels of transportation service into the future.

Competing Activities. At a second level lie decisions among several maintenance activities competing for limited maintenance resources. Given a fixed maintenance budget, any increase in the level of maintenance quality provided under one activity is usually accomplished only at the expense of decreased levels of quality in other activities. Therefore a manager faces the problem of allocating resources in such a way as to remain within budget while minimizing adverse impacts (both short and long range) on the utility, safety, and service life of the highway system.

Timing. At a third level there exists for each maintenance activity a tradeoff between the timing and the intensity of the action to be taken, commonly discussed as a question of "deferred maintenance." The impacts of deferred maintenance must be assessed in terms of, first, the costs of performing perhaps more extensive maintenance later; second, the differences in levels of service to users provided under the two maintenance options; and third, any reduction in the expected remaining life of the facility due to the deferred maintenance.

Commentary. Policy determinations of this type are inherently different from the decisions for which current maintenance management systems were designed. As a result, the models described earlier to predict maintenance requirements on the basis of supply lack the conceptual structure to address these broader management issues. Regression analyses and quantity standards drawn from historical data or existing practices implicitly include a particular level of maintenance performance -- namely, the standards to which the road system has been or is currently being maintained. Moreover, they assume a constant rate of deteriora-

tion throughout the road system. Thus the models are insensitive to changes in maintenance policy, and are incapable of evalauating either the costs or the impacts of alternative policies. Moreover, to the extent that the regression models predict directly the costs (or labor manhours) required, without computing first an estimate of damage repaired, they deal with work outputs rather than inputs, and are therefore ill-equipped to treat variations in input values (such as productivity, unit costs, or maintenance technology) among geographic regions or over time.

Required Approach. In general, to be able to evaluate competing maintenance (and investment) strategies requires a fundamentally different approach to maintenance prediction, looking at the demand for maintenance as well as supply. The reason is that different maintenance policies are implicitly statements on particular levels of road quality to be retained or restored. However, the workload (and by implication, the costs) required to achieve a given quality depend upon the prior condition of the road system -- i.e. the total maintenance backlog or deficiency caused by normal wear and tear, aging, and increased probability of failure. In an analytical sense maintenance may thus be viewed as a controlled response to the physical state of the highway network, to upgrade or retain highway quality to an acceptable level.

Treating maintenance as a demand-responsive operation requires that three additional concepts be introduced within existing management models. The first is that predictions of future maintenance effort and costs cannot be extrapolated from past trends, but rather must be based upon structural and operational deficiencies in the road system caused by use and deterioration. The second is that in designing models to be sensitive to the implications of different policies, there must be unambiguous statements of the maintenance policy itself, defining the types of future corrective actions to be taken, and when and where they are to commence. The third is that new relationships need to be identified between the as-maintained state of the highway network and the economic and non-market impacts to both the road agency and the motoring public, providing a measure of the benefits (or disbenefits) of each policy at the costs incurred above.

Since this demand-responsive approach is founded upon the prediction of road condition, it follows that any corrective action that restores the highway condition in some way needs to be accounted for. Thus the scope of this approach must be given an expansive interpretation, to include the relevant effects of betterments, rehabilitation and reconstruction, with those of maintenance. This view simply reflects the common-sense notion that capital investments do in fact influence the future demand for maintenance, and vice versa. Moreover, in this sense the demand-responsive methodology provides a fundamental engineering and economic basis for evaluating maintenance policy against alternative investment strategies.

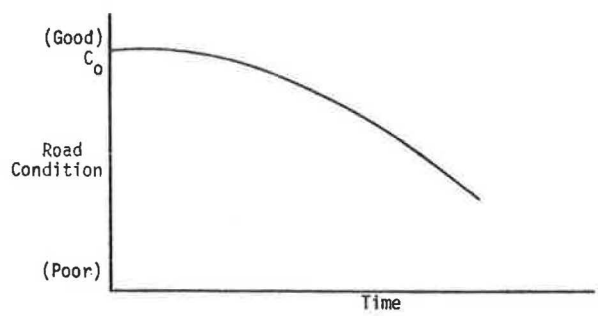
Schematic illustrations of the concepts underlying the demand-responsive approach will be shown in Figures 1 through 8 to be introduced below. The curves in Figures 1 through 8 represent models which, in actual maintenance management systems, would be developed individually for each element of the highway system -- pavements, bridges, drainage systems, signs, and so on -- or for each maintenance activity. For simplicity and generality in the following discussion, however, let us consider these curves for the time being to represent generalized relationships, applicable to a composite maintenance activity over the highway system as a whole.

Maintenance Level of Effort and Costs

Figures 1 through 3 identify those data necessary to predict maintenance level of effort and resulting changes in road condition as a function of different maintenance policies. These data also form the basis for the estimation of future maintenance costs as a function of policy.

Road Deterioration. The changing state of the road system over time is captured within a deterioration relationship defining the system's capacity to withstand the effects of time, traffic loadings, and the environment, as shown in Figure 1. For generality we define road "damage" as any degradation in road condition from its as-constructed state, and "deterioration" to be the net result of accumulated damage. The initial condition C_0 and rate of deterioration depend upon the quality of initial design and construction, and upon past maintenance performed. Thus the deterioration relationship in Figure 1 provides the engineering basis on which one may investigate different maintenance versus investment options.

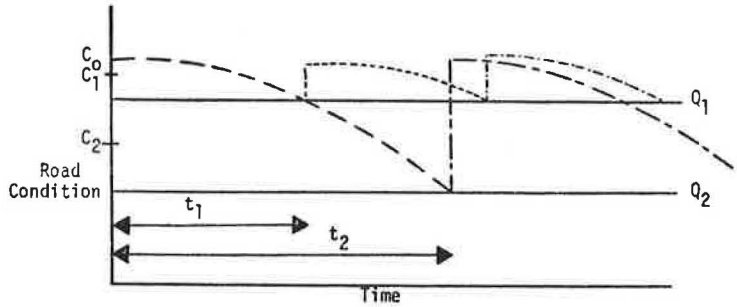
Figure 1. Determining maintenance level of effort under a demand responsive approach: deterioration relationship.



Quality Standards. Maintenance policies may be expressed through "quality standards" defining thresholds at which work should be performed. The interaction between two alternative quality standards, Q_1 and Q_2, and respective road system conditions is illustrated in Figure 2. The different quality standards result (not unexpectedly) in two different trends in road condition over time. If we adopt a simple time average for illustration, the higher quality standard Q_1 results in a higher average system-wide condition C_1. Also, the frequency of maintenance under Q_1 is greater than that under Q_2, in that $t_1 < t_2$.

Under this approach quality standards have a unit of measure commensurate with that of the deterioration model. Decomposing the condition of the road system into its constituent elements, we see, for example, several indices appropriate for pavements. One is a measure of pavement serviceability, such as AASHTO's Present Serviceability Index (PSI), or Canada's Ride Comfort Index (RCI). A second would be a measure of surface damage, such as skid number (SN), roughness value (R), cracking index (CI), or mean rut depth (RD)

Figure 2. Determining maintenance level of effort under a demand responsive approach: quality standards defining thresholds.

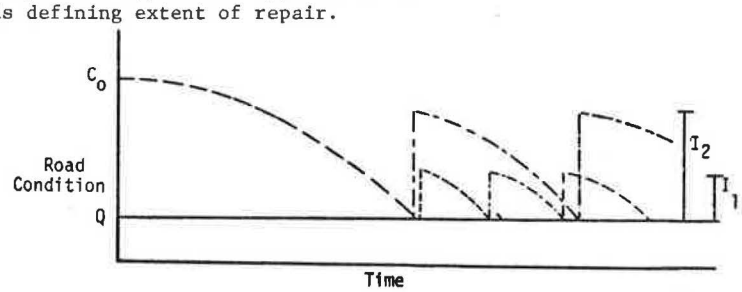


defined by many states employing surface measurement equipment. A third might be a measure of available pavement capacity or response, such as dynamic deflation. Analogous measures could be established for other highway elements; e.g. lineal feet of guardrail damaged, area of bridge deck damage, and depth of siltation in culverts, to name a few.

For some highway elements, however, it may be theoretically possible to identify a physical measure of condition, but it may not be practical to use within a quality standard. Consider, for instance, the replacement of defective signal lamps, which usually must be done soon after failure. A possible measure for signal condition would be "probability of lamp failure within the next so-many months," but it is typically more convenient for the quality standard to use instead some frequency of lamp replacement which anticipates lamp failure. Figure 2 demonstrates that for a given deterioration curve, specifying the frequency of maintenance is equivalent to establishing some implicit quality level. This concept may be used to advantage in the identification of quality standards for particular maintenance activities.

Variation in Application of Standards. In Figure 2 it was assumed in each case that all current maintenance deficiencies were fully corrected. A more realistic situation, however, is that at any given time only a portion of the accumulated damage in the system is repaired through maintenance. From a policy perspective this type of decision can be controlled by how the quality standards are applied on a system-wide basis. Figure 3 illustrates two different applications of a given quality standard Q: one results in relatively frequent but minor correction I_1, while the other undertakes less frequent but major I_2. Note that neither I_1 or I_2 are sufficient to restore the system to its initial condition at construction.

Figure 3. Determining maintenance level of effort under a demand responsive approach: application of quality standards defining extent of repair.



There are three general ways in which the application of quality standards may be varied to produce different levels of repair. One is by adjusting quality standards among different activities which in some sense substitute for one another. For example, the extent to which corrections of pavement damage are remedied by overlays (as opposed to routine maintenance activities) will influence the magnitude of I achieved overall in a given work period. A second way is by assigning different quality standards among various links within the network. Since repair of some locations will implicitly be given priority over other locations, this variation in quality standards will also affect the extent of improvement I on a system-wide basis. Finally, quality standards (and their associated maintenance actions) may be restricted to those classes of damage most critical to road integrity and performance. For example, the "percent of pavement area cracked" may be interpreted to include only cracks greater than a certain width; "guardrail damage," to comprise broken and severely deformed sections, but not dented ones; and "grass height requiring mowing," evaluated only within a certain distance of the pavement edge, but not over the entire mowable area. Qualifications of this type intentionally limit the extent of improvement I in comparison to the total deterioration absorbed by the system.

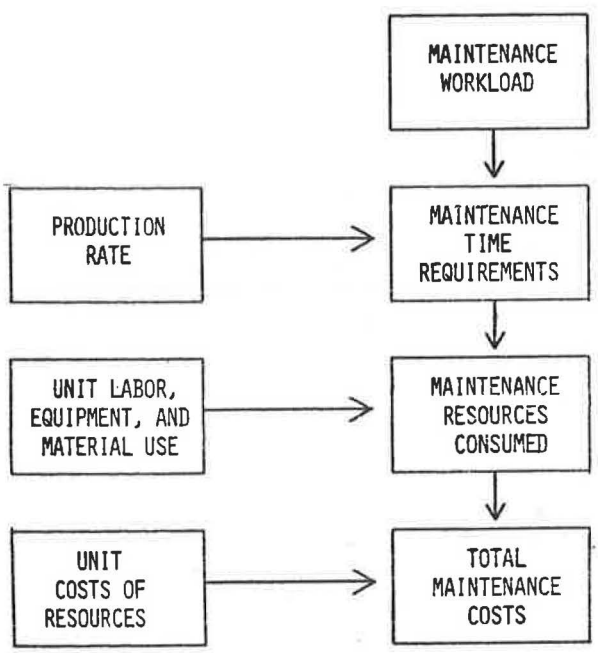
Maintenance Costs. In Figures 2 and 3 the total maintenance level of effort over the system life under policy Q is a function of the product of the frequency of maintenance (proportional to 1/t) and the improvement in condition I each time maintenance is performed. The costs of different maintenance policies may then be computed by calculating the costs to accomplish respective improvements I, discounting these at an appropriate rate according to their projected time of occurence t, and summing the discounted totals for each policy alternative.

From our discussions earlier, the units of measure of system condition C, and therefore of the extent of improvement I, may be in terms of serviceability indices, damage indices, or road response indices. Regardless of the measure of I employed, however, it is obvious that an improvement in condition must be accompanied by the correction of a certain amount of damage, whether for example in square feet of pavement cracking filled, lineal feet of guardrail straightened, number of signal lamps replaced or lineal feet of drainage lines cleaned. The explicit measure of damage corrected we will call the maintenance workload W. In mathematical terms, then, an improvement in condition I implies a particular maintenance workload W, or $I \rightarrow W$. (In some cases the units of I and W may be identical. In others a function must be identified relating I and W.)

Maintenance workload provides the basis for estimating maintenance costs, as shown in Figure 4. To a given workload may be applied a production rate (e.g. average number of damage units repaired per day) to obtain overall crew time requirements. Workload and crew time may be translated into resources consumed (manhours, equipment hours, materials quantities) through unit labor, equipment and materials usage (e.g. number of laborers or pieces of equipment per crew, materials quantity required per unit of damage), all a function of the maintenance technology employed. Finally, resource requirement may be multiplied by the respective unit costs of labor, equipment and materials to obtain total maintenance costs desired.

The relationships in Figure 4 point to the supply side of maintenance, and are thus similar to models employed in contemporary maintenance management systems discussed earlier in this paper. The difference between the two approaches (that in Figure 4 versus existing models) is in the estimation of the workload itself. Whereas existing models predict workload (or some proxy for workload) directly from past experience, in Figures 2 and 3 we have predicted it based upon demand-side considerations of system condition and maintenance policy. The separation of demand-side and supply-side contributions to maintenance costs (represented by Figures 2, 3, and 4 respectively) is a particularly valuable management capability where, as identified at the beginning of this paper, several aspects of highway maintenance and operation are changing simultaneously.

Figure 4. Calculation of the maintenance costs.



For example, the demand-side relationships in Figures 2-3 account for not only variations in maintenance policy, but also for the effects of higher (perhaps unforeseen) traffic volumes and weights, unusually adverse weather conditions, and changes in highway design and construction standards. For a given maintenance policy the contributions of these effects to maintenance costs are transmitted via changes in the maintenance workload.

On the other hand, the supply-side relationships in Figure 4 account explicitly for changes in maintenance technology, work practices, supervisory requirements, crew productivity, and unit costs of maintenance resources. The contributions of these factors to total maintenance costs are superimposed upon, but independent of, the costs attributable to total workload arising through maintenance demand.

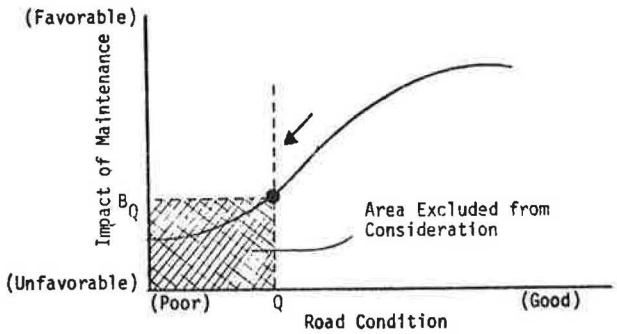
Maintenance Impacts

Better maintenance policies will generally cost more. In evaluating the merits of different policies, therefore, one cannot look only at the costs incurred, but must also judge whether what is gained under higher quality standards is worth the additional dollars spent. Fortunately, the process of predicting the impacts of maintenance is directly compatible with the demand-responsive concepts introduced in Figures 2-3 earlier. The mechanics of assessing maintenance impacts are illustrated in Figures 5-8.

The relationship needed to predict maintenance impacts is illustrated schematically in Figure 5. The measure of road condition shown on the abcissa is identical to that discussed in Figures 1-3. Consistent with other aspects of our example, maintenance impacts are shown in very general form on the ordinate. These impacts may in fact encompass diverse results of maintenance performance, such as the contribution to remaining road life, decreases in user operating costs, and increases in motorist safety and convenience. (For simplicity we assume, both in Figures 5-7 and in the discussion below, that maintenance impacts are cast in the form of relative benefits. However, they may also be represented as disbenefits as for example, in added congestion costs due to road occupancy for maintenance. The conceptual approaches to both benefits and disbenefits would be similar.)

As before, the condition denoted by the quality standard Q defines the threshold at which maintenance will be performed; Q is a control variable expressing maintenance policy. In Figures 2-3 it was assumed that the system condition does not fall below Q. From Figure 5, then, the minimum level of impacts that can be experienced in the road system is B_Q, and the points lying within the hatched area denote conditions and impacts that should be absent within a road system subjected to a quality standard Q.

Figure 5. Determining maintenance impacts under a demand responsive approach: maintenance impact relationship.



Performing maintenance will improve the system in some sense, thereby also providing positive impacts to the road agency or the motoring public. Figure 6 illustrates this for the case of modest maintenance improvement I_1; and Figure 7, for a more substantial improvement I_2. (Refer to Figure 3 for illustrations of different levels of maintenance improvement.) Both of these improvements are gauged from the same quality level Q. On the other hand, Figure 8 illustrates the effects on maintenance impacts of varying both the quality standard Q and the associated level of improvement I.

Figure 6. Determining maintenance impacts under a demand responsive approach: benefits from maintenance.

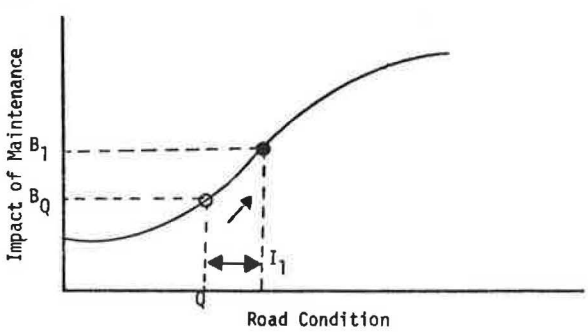
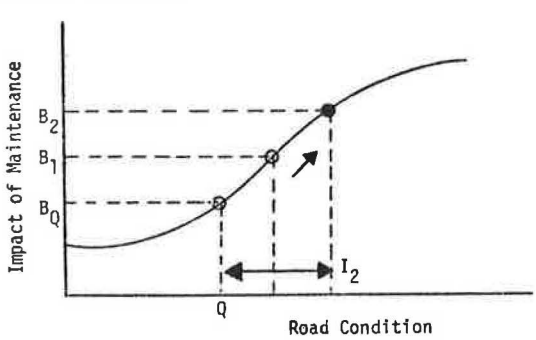


Figure 7. Determining maintenance impacts under a demand responsive approach: greater benefits from increased maintenance.

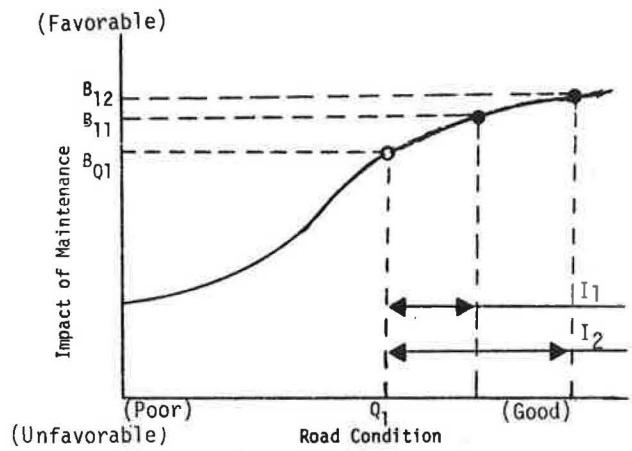


The benefits of maintenance accrue among several aspects of highway structure and operation. We have chosen three major areas of impacts -- preservation of the road investment, user travel and operating costs, and safety -- for initial investigation under a research project for FHWA. Others could also have been chosen -- highway aesthetics or environmental effects, for example. The point is that some, but not all, maintenance impacts can be reduced to monetary benefits. This fact in turn implies a need for a multidimensional analysis of maintenance impacts above and beyond traditional approaches such as benefit-cost comparisons.

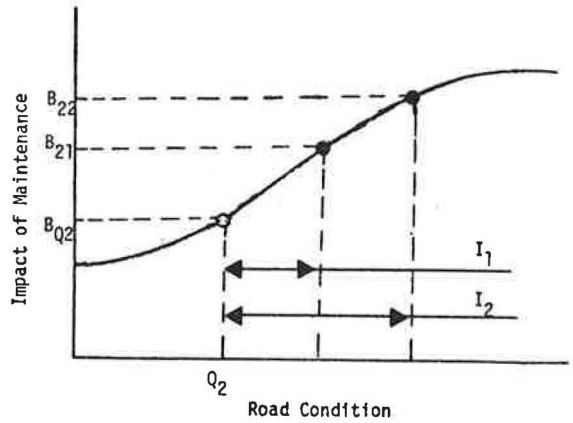
Another point has to do with the magnitude of benefits received for a given improvement in road system condition. This relationship depends upon the shape of the impacts vs. road condition function, which we have hypothesized in Figures 5-8 to take the form of an S-curve. The assumption here is that the marginal benefits of maintenance performance are greatest within some mid-range of highway system condition. If the system has deteriorated completely, then virtually nothing is to be gained by doing modest amounts of maintenance; wholesale repairs, overlays, and rehabilitation are needed instead to restore more favorable impacts. On the other hand, performing excessive maintenance can lead to diminishing returns. In

Figure 8. Maintenance impacts under different quality standards and levels of improvement.

A. Maintenance improvements under higher quality standards.



B. Maintenance improvements under lower quality standards.



such cases, the costs of providing this very high degree of maintenance may be questioned, particularly if the reallocation of maintenance dollars among other maintenance activities (or road sections) presents the possibility for greater marginal benefits.

Management Implementation

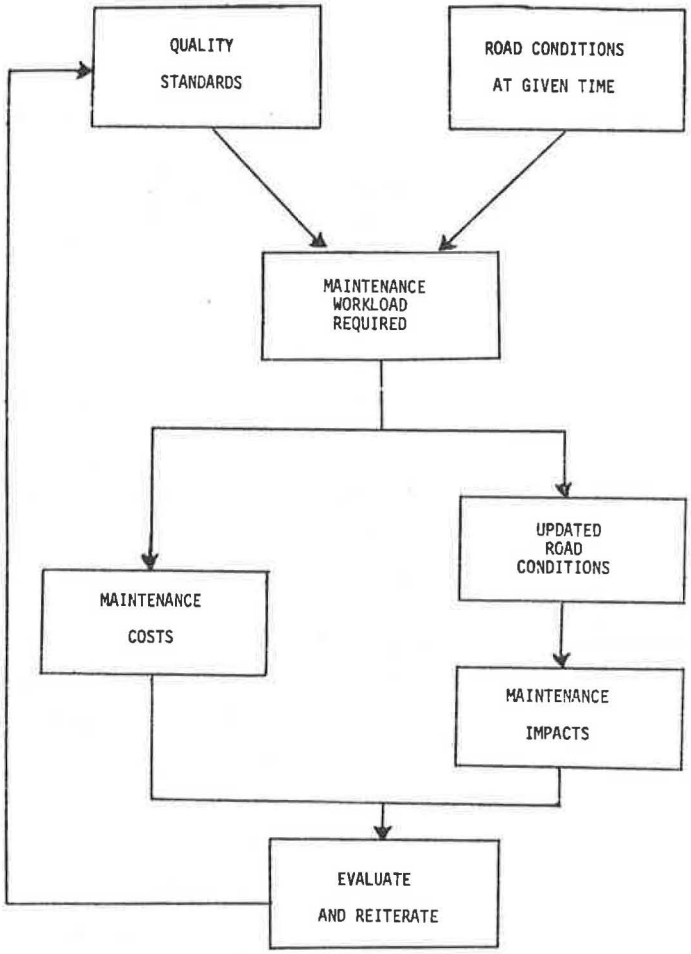
The concepts embodied in Figures 1 through 8 collectively define a management approach to evaluating future maintenance policies or strategies. Organization of these ideas within a unified structure is shown in Figure 9, whose key elements are summarized below.

Annual maintenance is viewed as a demand-responsive operation; that is, a function of the demand accumulated in the highway system in a given year. This deterioration can be estimated from the initial condition of the system (i.e. its as-constructed quality), its rate of deterioration over time, and past maintenance performed. Beyond these physical conditions, however, maintenance workload requirements are also subject to policy decisions defining the type, location, and extent of work to be provided. Maintenance policies are expressed through quality standards specified for the set of maintenance activities over all sections of the road system. Elements of this demand-responsive methodology were introduced in Figures 1-3 and are summarized in the top half of Figure 9.

For a given strategy the estimated maintenance workload may then be costed according to the procedures set forth in Figure 4. At the same time, the simulated accomplishment of this maintenance will improve the condition of the road system, generating a set of maintenance impacts as envisioned in Figures 5 through 8. The calculation of costs and impacts of a given strategy are thus seen as parallel computations in Figure 9.

Maintenance policy evaluation entails a comparison of both relative costs and relative impacts between the strategy under consideration and other maintenance and investment options available. If maintenance impacts could be reduced completely to monetary units, then techniques such as benefit-cost or net-present-value analyses could be applied to determine the optimal strategy. However, in the more general case where impacts are multidimensional, it becomes difficult to state what the "best" maintenance strategy should be. We have

Figure 9. Approach to demand-responsive maintenance management.



therefore suggested in Figure 9 an iterative approach, wherein the results of one strategy can be analyzed to suggest further options more favorable in terms of costs, impacts, or both. By adjusting quality standards through successive trials, maintenance managers can identify a maintenance policy encompassing acceptable (or at least non-objectionable) costs and impacts. Although this procedure requires a subjective assessment of the impacts of different strategies, its value lies in the fact that the consequences of performing or, alternatively, deferring different highway maintenance activites are explicitly spelled out (with costs) for each maintenance policy considered.

Broadly speaking, the approach in Figure 9 may be applied to address two types of situations. The first situation would be to constrain the values of the impacts desired -- in other words, to establish some range of road system benefits that must be sustained through maintenance and rehabilitation, and not to allow the road system to degrade below the established threshold. Through the iterative procedures in Figure 9 one could infer both the maintenance policies and costs necessary to accomplish this target level of service. The second type of situation would be to constrain costs -- in other words, impose a budget limitation. The iterative methodology in Figure 9 could again be applied, this time to vary maintenance policies to attempt to maximize (in a subjective sense) favorable impacts while remaining within the cost ceiling.

Applications

The demand-responsive concepts above are now the subject of research, to formulate them within models of practical use in maintenance policy planning and management. Two projects are worthy of note.

The first project, completed in 1978, involved the design and development of a statewide highway maintenance management system for the Commonweath of Massachusetts. Included within this system is a budgeting component to enable the state to predict maintenance work requirements and costs one to two years hence, for submission as part of the state's routine process of legislative fiscal review and approval. This budgeting system is unique in that it employs numerical quality standards as expressions of maintenance policy, and analytic predictions of resulting system conditions and maintenance impacts. The relevant models were developed in preliminary form for the 50-odd activities to be managed under the system, and are described in (2). Massachusetts is now completing its collection of road inventory data and maintenance unit cost and production information necessary to implement the budgeting procedure.

As a follow-on to the Massachusetts work, we are now conducting a DOT University Research Project through FHWA to formalize the concepts of demand-responsive maintenance predictions and to derive generalized models of deterioration and of maintenance impacts, with associated quality standards, for the activities listed in Table 1. Models will be developed in analytical form suitable for inclusion in maintenance planning or management systems if desired.

Table 1. Candidate activities for FHWA study.

1. ROAD SURFACE
   - Flexible Pavement Patching
   - Rigid Pavement Crack and Joing Sealing
   - Flexible Pavement Overlays
2. ROADSIDE AND RIGHT OF WAY
   - Clean, Reshape Ditches
   - Litter Pickup
3. TRAFFIC SERVICES
   - Pavement Lane and Edge Shaping
   - Relamp Signals
4. STRUCTURES (Conditional)
   - Deck Repair
5. APPURTENANCES (Conditional)
   - Repair Guardrail

As examples of the types of models proposed, Figures 10 and 11 give two examples drawn from our earlier Massachusetts work, showing respectively deterioration and impact models for the activity of placing thin surfacings to improve pavement skid resistance. Figure 10 shows plots of exponential functions relating decline in average skid number (ignoring seasonal effects) to cumulative traffic levels. The families of curves illustrate sensitivity of the model to calibration parameters included in the exponential relationship. Similarly, Figure 11 illustrates the projected effect of the decline in average skid number on the ratio of wet accidents to total accidents. Again, the family of relationships is attributable to the calibration parameters employed (Note that the "B" term in Figure 11 is different in meaning from that in Figure 10). The quality standard in this case is expressed as the minimum acceptable skid number that is to be allowed. Analogous models and standards were developed for other pavement and highway maintenance activities as well.

The DOT University Research Project with RHWA is scheduled to be completed in June 1981.

Acknowledgements

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Figure 10. Skid relationship.

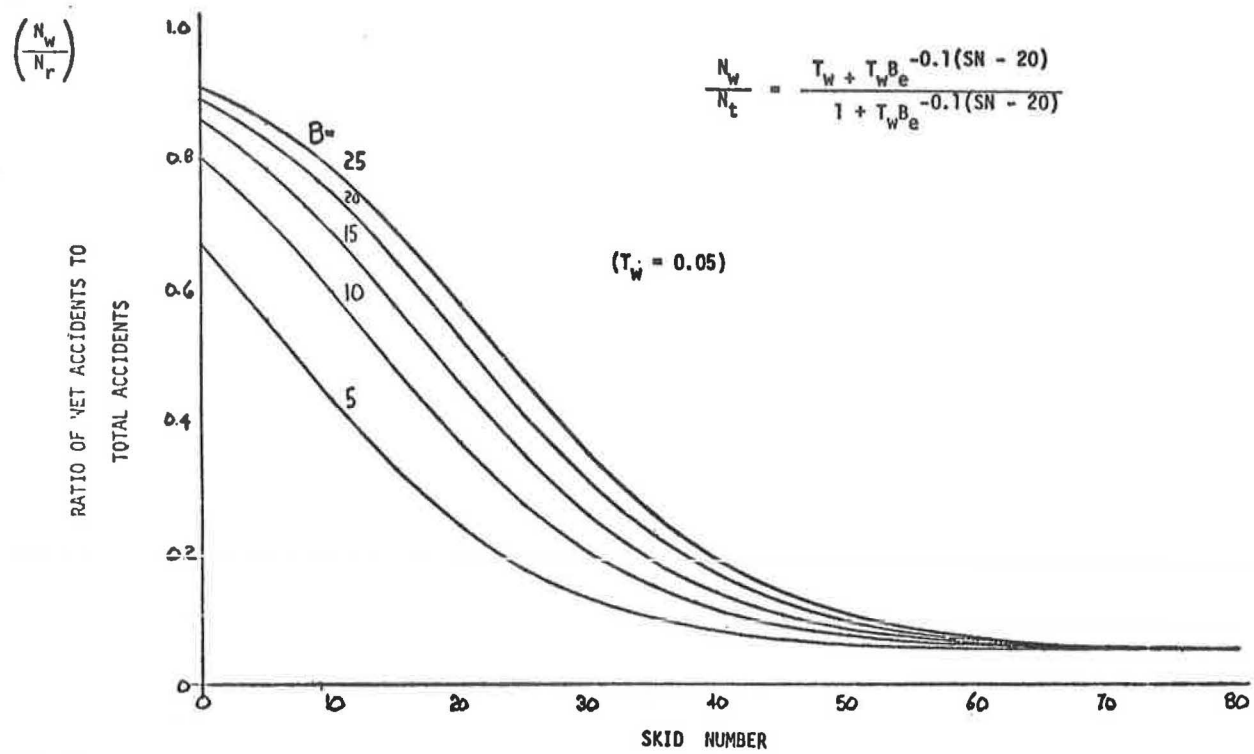
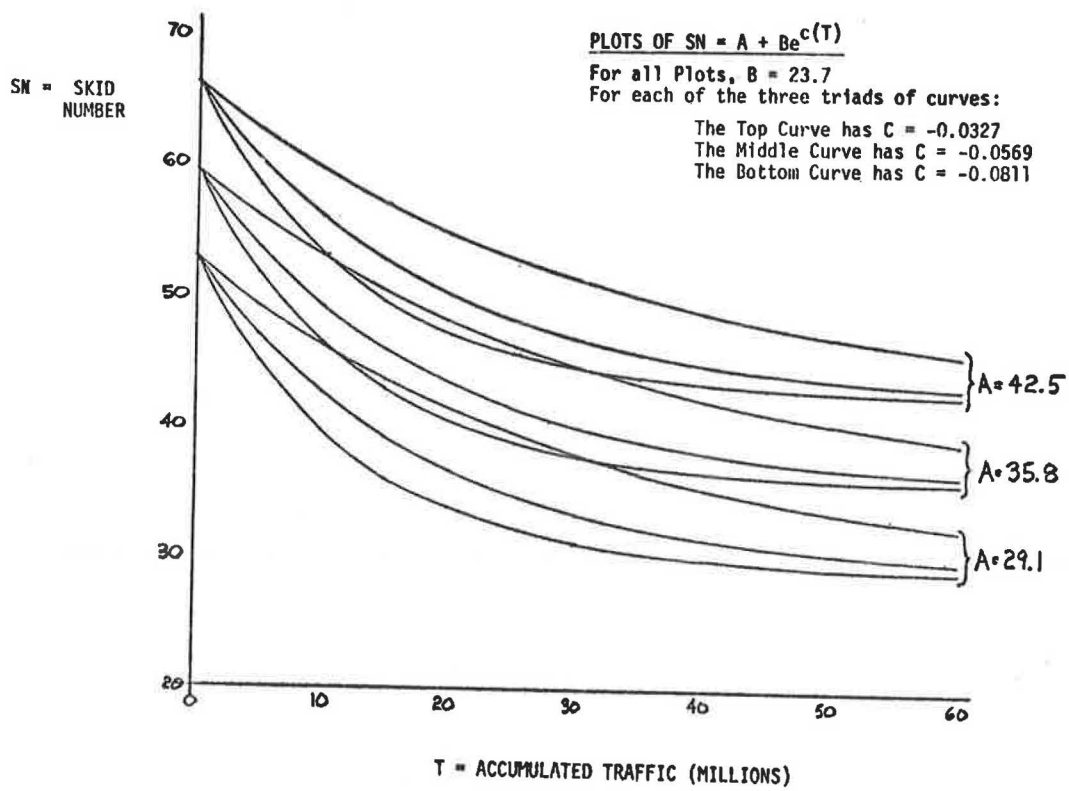


Figure 11. Model of wet pavement accident frequency as function of skid number.



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