# A Process for Determining Financial Requirements for Road Maintenance and Optimal Maintenance Measures

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ABSTRACT

Under the sponsorship of the Federal Ministry of Transport, Federal Republic of Germany, a process has been developed to improve forecasts of the budgetary requirements for long-term maintenance of the national road network and to assist in making economically optimized road maintenance decisions. This process (designated the strategy model process) relies on a number of models that, in general, include the service life of road sections and the timing, type, and cost of various alternative maintenance measures as independent stochastic variables. Examples are provided to illustrate how the strategy model process can be and has been used as a practical instrument for decision makers.

A prerequisite for introducing a management system for road maintenance is a rationale for making economically optimized decisions. The most important factors in this decision-making process are as follows:

1. Establishing the requirement for medium- and long-term financing,
2. Selecting the road sections that need maintenance and ranking these sections according to urgency (priority), and
3. Determining the individual measures to be implemented from technical and economic viewpoints; examples of relevant decisions are as follows:
   - Materials and construction techniques,
   - Design and strengthening strategies,
   - Maintenance strategies,
   - The optimal time for maintenance measures, and
   - Construction method as related to the length of the sections selected and traffic management along the sections under construction.

The purpose of this paper is to show how requirements for funding road maintenance are forecast in the Federal Republic of Germany. Factor 1: indicate what principles are used to arrive at optimum decisions within the framework of road maintenance. Factor 3: select road sections for maintenance and rank them according to priority. Factor 2: rely on an assessment of the pavement condition; Mr. Schoenberger has already discussed this subject in another paper in this Record.

## DETERMINE THE FUNDING NEEDED FOR ROAD MAINTENANCE

Until the present the existing processes provided only a rough assessment of the funding needed for road maintenance. These relied on "depreciation calculations" based on time scales for the various elements of the road, and on "deduction calculations," which take into account those elements of the road that drop out, because they have reached a theoretically established service life. Statements based on such global forecasts are not justified for projecting future maintenance requirements.

For this reason a process has been developed under the sponsorship of the Federal Ministry of Transport that, based on the available data, should provide more accurate forecasts than have been possible hitherto. This process (called the strategy model process) involves the construction of models regarding type, part, and time scales for the relevant maintenance measures. Each group of road sections that can be described precisely, that is, to which individual characteristics can be attributed such as road strengthening design and traffic load is formed into precisely defined strategy models. Naturally, the process can be used only for those sections of the layout for which a strategy model is meaningful, for example, a pavement. The maintenance requirements of other parts that are not suitable for assessment using a model must continue to be assessed approximately as hitherto through depreciation calculations. This applies for example to the subsoil.

Briefly the most important elements of the strategy model process are model building, data acquisition, and model simulation.

### Model Building

A strategy model includes type of maintenance measure and service life as parameters. Figure 1 shows a simple strategy model with fixed service life, $\Delta t$, and three types of maintenance: new construction (B), rehabilitation (I), and reconstruction (E). Maintenance measures must be considered when important parameters (for example evenness and serviceability) fall below values established as acceptable. Thus, the service life (or the period between maintenance measures) depends on changes taking place in the pavement condition over time and in particular on which characteristic is assessed as having reached a minimum value in view of the traffic volume.

Accordingly the model parameters service life and type of maintenance measure must be determined as functions of the expected changes in the pavement condition with time and the desired minimum quality. These depend on a large number of parameters, the most important of which are listed below.

- Type of pavement,
- Design,
- Traffic load,
- Climate,
- Subgrade and subsoil characteristics,
- Topography,

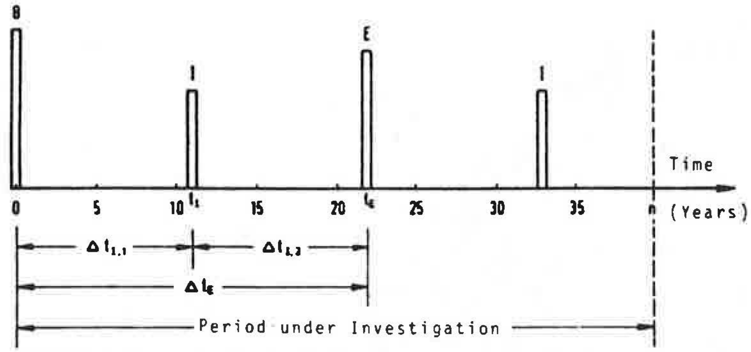


FIGURE 1 Example of a simple, fixed strategy model where B = new construction, I = rehabilitation, and E = reconstruction.

- Quality of execution of construction, and
- The required minimum quality (based on serviceability and safety) depending on the type and importance of the road.

Not all parameters can be considered in constructing the model. For some the effect of the various dimensions on the time-dependent changes in pavement condition cannot as yet be quantified. Furthermore, some data cannot be acquired readily. Finally too detailed a differentiation between models for forecasting financial needs, having regard for the ever present uncertainties in model construction, would be both unnecessary and unjustified. Thus, until now the parameters have been limited to type of pavement, design, traffic load, and type of road.

The "characteristic model groups" have been constructed accordingly. It was assumed that in the relatively small area of the Federal Republic of Germany no significant climatic differences arise.

The multiplicity of parameters and the existence of uncertainties in determining the service life as a function of the parameters have been taken into consideration by including in the model the following as independent stochastic variables.

- Service life,
- Parts of the various types of maintenance measures adopted in practice, and
- Costs of maintenance measures.

A comprehensive questionnaire to be completed by experts was devised to obtain the model parameters of service life and type of maintenance measure as well as "part of maintenance measure type." (It is not possible to report here the details of the methodology of the questionnaire). The following results were obtained from the questionnaire:

- Mean values of the various types of measures (indicated by the letters L,M,N...R in Figure 2), as well as mean parts of 10 percent for the M type of measures and of 20 percent for the O type of measures.
- Empirical reliability distributions, that is, time distributions of the intervals between maintenance measures (service life, $\Delta t$, between maintenance measures) as a function of types of measures (Figure 3). For example, following the execution of the maintenance measure designated by the letter N, there is a 50 percent probability that $\Delta t$ = 10 years, and a 4 percent probability that $\Delta t$ = 20 years.

A weighted reliability distribution can be constructed from the parts of maintenance measure types (Figure 2)

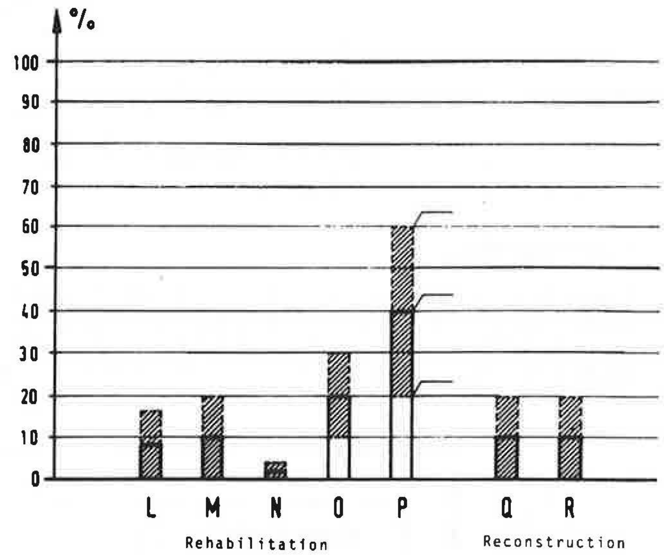


FIGURE 2 Parts of maintenance measures (L, M, N, . . . R).

and any relevant reliability functions (Figure 3). (The weighted reliability distribution is shown as a dotted line in Figure 3).

## Data Acquisition

To establish the cost requirement and to construct the model the existing state of the road surfaces must be divided according to the previously mentioned characteristic groups. Furthermore, the series of investment periods, that is, the times of initial construction (new construction B) or of the last complete reconstruction (E) must be known. These data may be either (a) related to specific roads or (b) on the basis of statistics.

In the "object-related acquisition" the data are collected section by section of the road. On the basis of the results of the data acquisition the data are arranged according to a characteristic group and a given strategy model. It is possible to make corrections and changes so as to consider the existing pavement condition and other aspects (e.g., climate, subsoil, and subgrade characteristics). However, the data acquisition process is very expensive and is generally only recommended for highly differentiated road systems, for example, urban roads. For roads outside built-up areas (e.g., motorways and highways) it is quite adequate to arrange statistical data into characteristic groups.

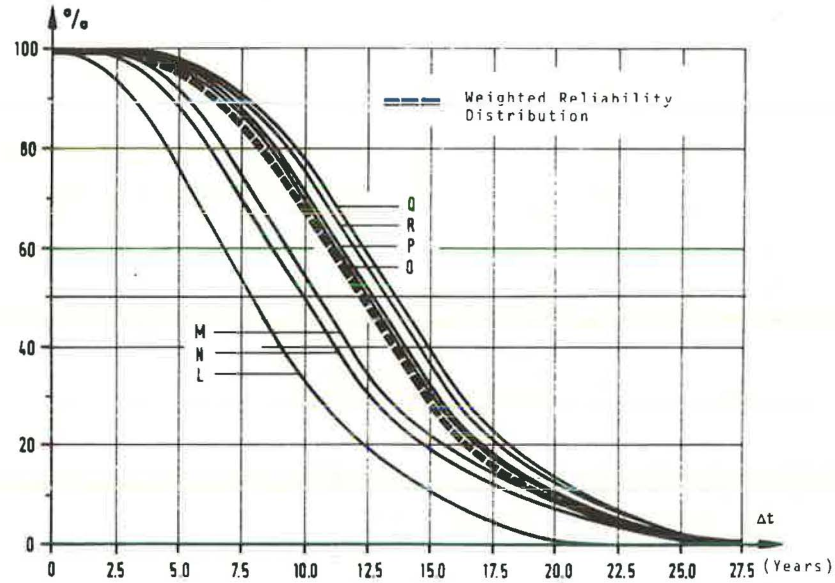


**FIGURE 3 Empirical reliability distribution curves of various types of rehabilitation measures.**

### Model Simulation

Figure 4 shows schematically the calculated financial needs obtained by means of the strategy models (maintenance models). The investment-time series must be established before the actual model simulation on the basis of "equal characteristic categories."

The empirical model functions are described on the basis of the distribution functions for the maintenance interval Δt, the parts of measures, and the cost of maintenance. The distribution functions are obtained from the following:

- Equal distribution of parts of maintenance,

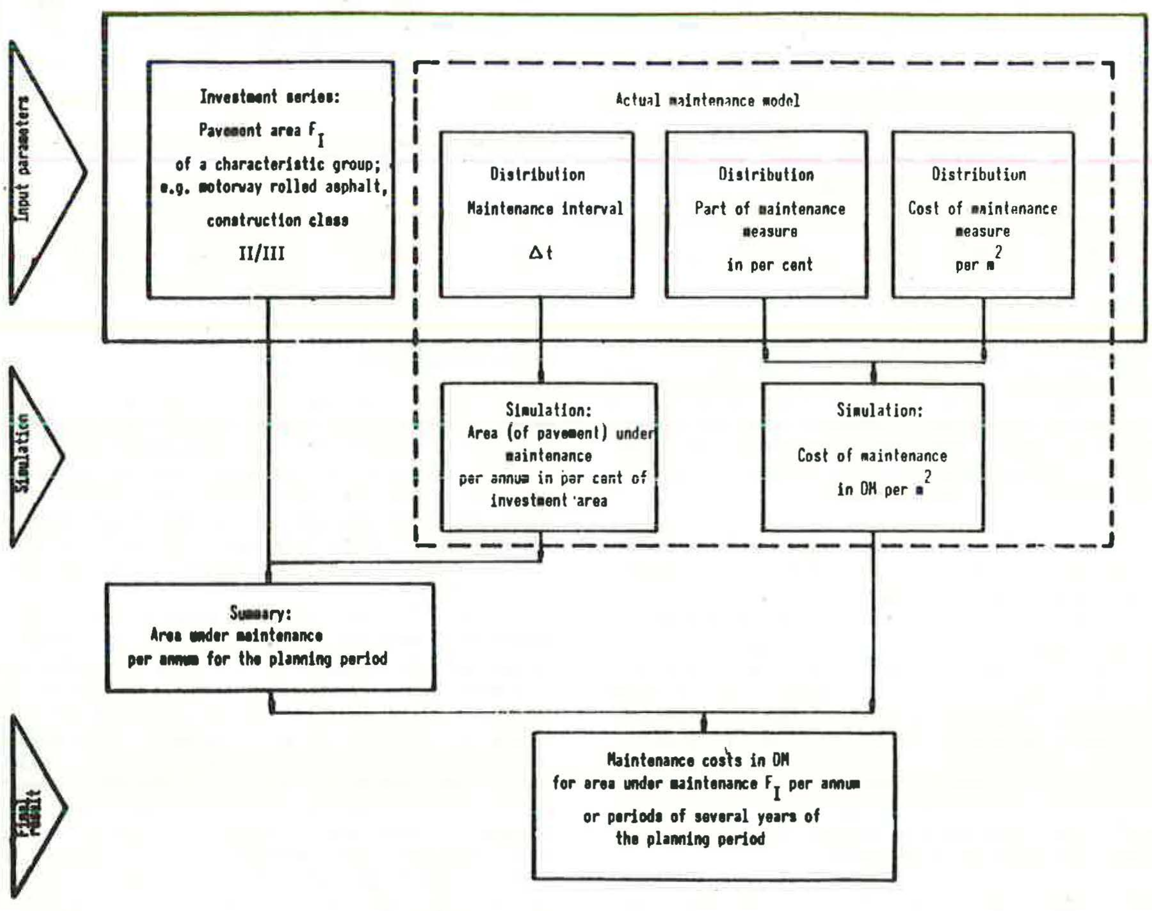


**FIGURE 4 Schematic representation of model simulation.**

- Normal distribution of the maintenance costs (to the extent that it is possible to make calculations based on fixed cost units), and
- Logistic distribution for the maintenance interval Δt (Figure 5).

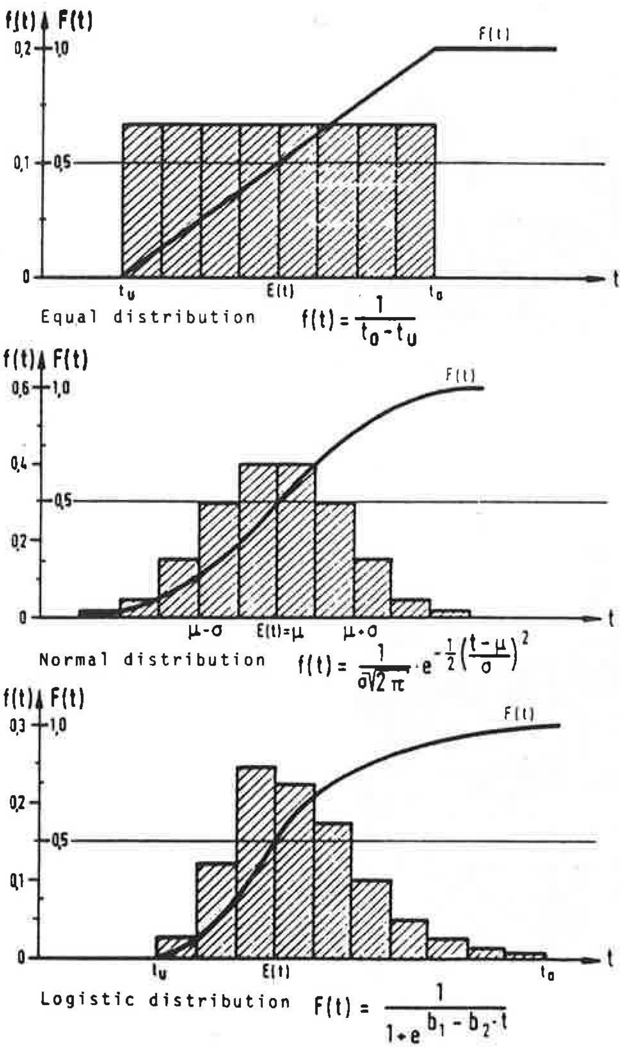


FIGURE 5 Distribution functions.

The Monte Carlo method was used for the computer-based simulation of these probability distributions.

In summary, the calculation may be illustrated by the following abbreviated example. First the distribution of maintenance costs per square meter of pavement (Figure 7) is established from the equally distributed parts of maintenance measures (Figure 2) and their unit costs (Figure 6). The percent distribution of the road maintenance surfaces for an investment year through the period under consideration is obtained from the corresponding weighted reliability distributions (Figure 2) in regard to the results of various maintenance measures according to Figure 8 (here it is assumed that two different types of maintenance measures follow each other periodically). The portion of pavement subject to maintenance per year expressed in percent of the total available road stock of a characteristic group is projected (see Figure 9, which represents a period of 20 years) on the basis of this model's distribution of pavements under maintenance for one investment year (Figure 8) and the investment-time

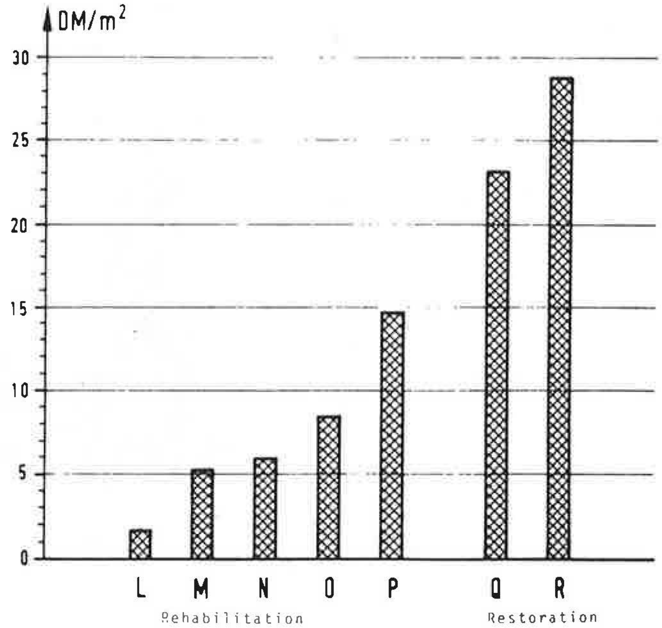


FIGURE 6 Unit costs of types of maintenance measures.

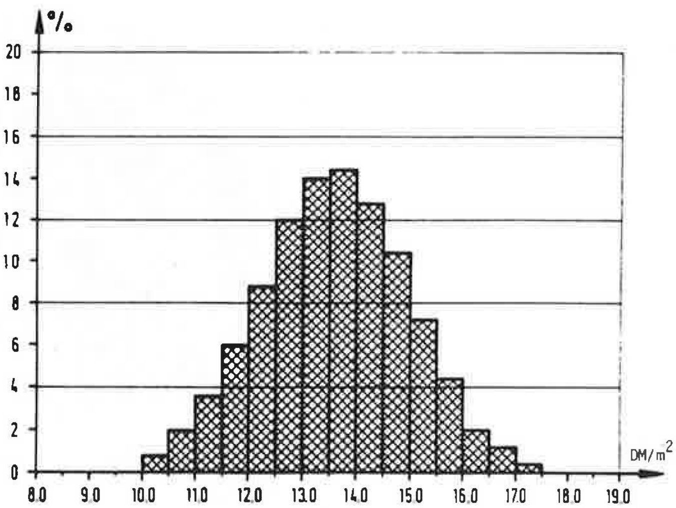


FIGURE 7 Probability distribution of maintenance costs per m2 pavement area.

series for the total road stock in a characteristic group (Figure 10).

The relative maintenance cost per unit of surface area and cost per annum (Figure 11) for a given characteristic group of the road stock is calculated by multiplying the above mentioned portion of pavement subject to maintenance by the maintenance cost per unit of surface area (Figure 7). Multiplying that product by the total surface of the road stock yields the absolute annual cost of road maintenance of the pavement (no illustration).

However, for long-term planning projecting the costs for each year is not what is most needed. It is more likely that an estimate of average annual costs over a longer period is required. Accordingly Figure 12 shows the average relative cost per unit of surface area and per annum for a 5-year period.

## Concluding Remarks

As a result of the development work described and

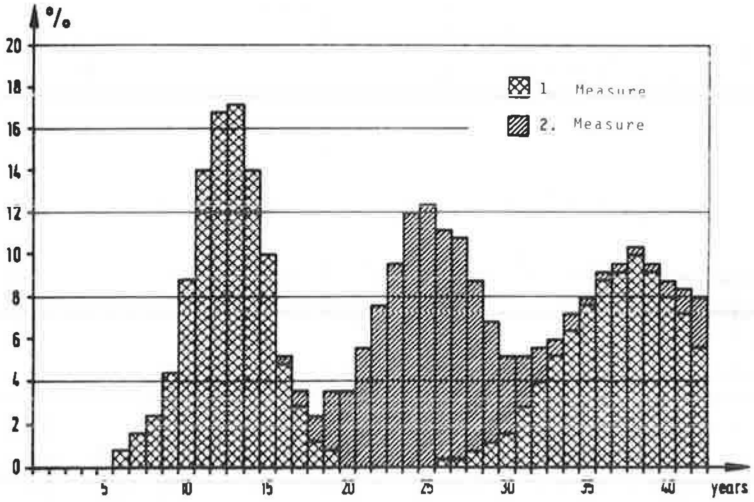


FIGURE 8 Percentage distribution of maintenance areas for an investment year.

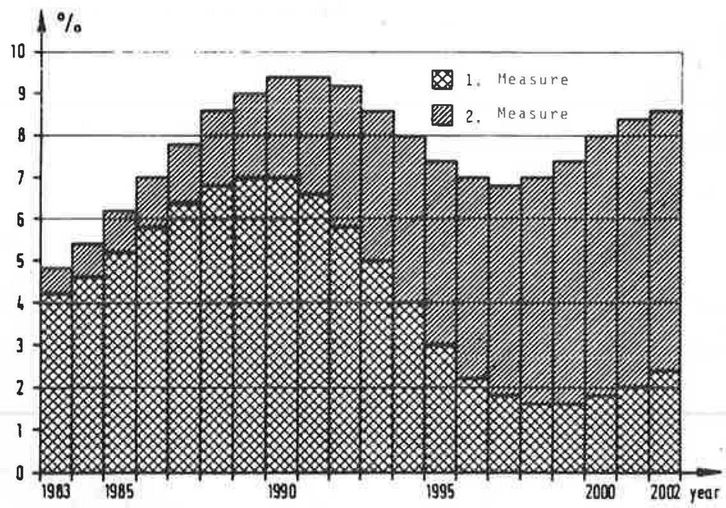


FIGURE 9 Extent of areas under maintenance per annum (percentage values of the available stock).

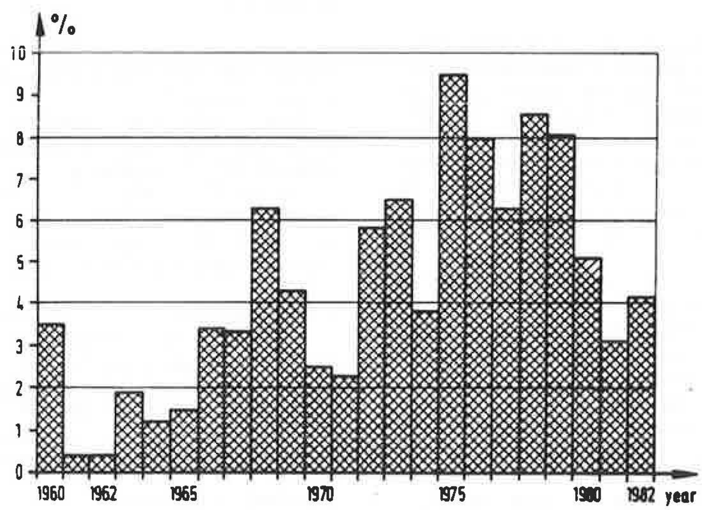


FIGURE 10 Investment-time series (percentage values) for the road stock of a characteristic group.

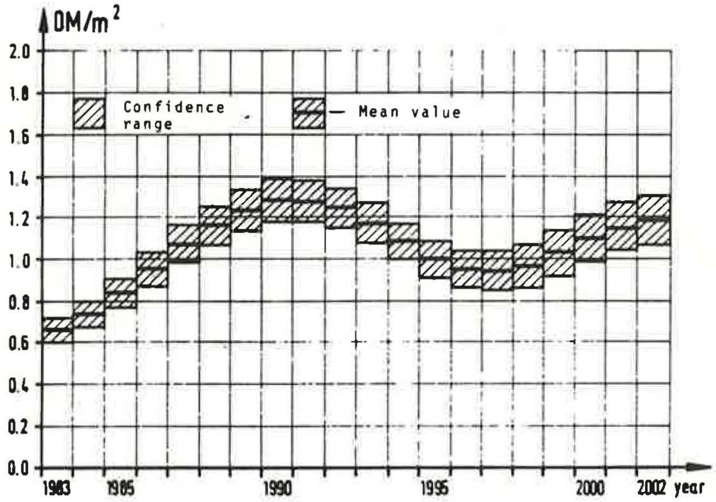


FIGURE 11 Relative maintenance cost per unit area and per annum.

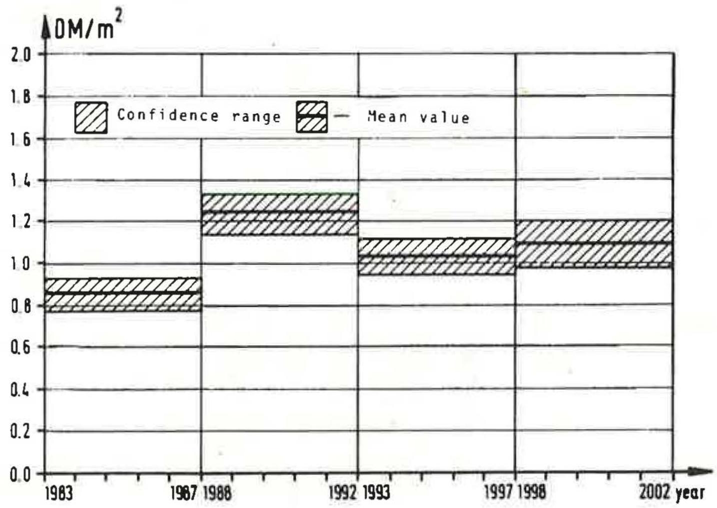


FIGURE 12 Mean of relative maintenance cost per unit area and per annum for 5-year periods.

illustrated in this paper, there now exists a widely applicable process for determining the future costs of the elements of a road, to the extent that they can be represented by a model. The program is flexible and allows one to examine any appropriate budget situation within given time scales, allocating any given limited models of maintenance measures.

For example in times of financial stringency, it might be most appropriate to consider models incorporating the most simple and inexpensive maintenance measures; these would result in a correspondingly short service life (such as measures of type L, M, or N with reliability functions shown in Figures 3 and 6, respectively). Following this, for subsequent maintenance measures, it would be necessary to use models that result in more costly reconstruction (e.g., types Q and R in Figures 2, 3, and 6). That is, a period of low-cost repairs would appropriately be followed by a period of more costly rehabilitation measures. It will be necessary to examine by economic studies, whether, and if so to what extent, such a maintenance strategy is meaningful and justifiable.

## OPTIMIZATION OF DECISION MAKING FOR ROAD MAINTENANCE

Optimization of individual decisions for maintenance measures--as already indicated in the introduction--has been carried out in a computer study sponsored by the Federal Ministry of Transport. This study distinguishes between

- Purely operational consideration of a budget for only the discounted costs of the public agency $\bar{S}$ (i.e., discounted for a given point in time) are considered, and
- Total economic consideration, for which the discounted costs arising through the road users $\bar{N}$ are also included.

Agency costs include new construction costs and the cost of maintenance and operation of the road; road user costs include the costs of journey time, vehicle operation, and accidents. In the total economic calculation, however, total road user costs are not included, but only the additional cost, $\Delta\bar{N}$, which is the additional cost over that of an ideal state. In cost-benefit calculations $\Delta\bar{N}$ results from including two additional user costs:

1. $\Delta\bar{N}_p$ resulting from the deterioration of serviceability of a pavement with time, and

2. $\Delta\bar{N}_B$ resulting from the slowing down of traffic because of maintenance measures at given sites.

The alternative measures may be compared on the basis of the advantages.

- For purely operational consideration: those that provide the lowest discounted costs of the public agency ($\bar{S}$ min), and
- Under total economic consideration: those that show the lowest discounted total cost (i.e., $\bar{G} = \bar{S} + \Delta\bar{N}$, or in other words the smallest sum comprising agency costs and additional users costs).

The following is one example of the many economic studies that have been carried out; it shows how the optimum economic point in time for carrying out road maintenance can be established.

Figure 13 shows the principal relationships between discounted costs and the intervals $\Delta t$ between given maintenance measures where two different trends (I and II) must be assumed for developing the pavement serviceability index (PSI). In the illustration (top left) the agency costs, $\bar{S}$, are shown, that is to say the cost of construction and maintenance. Where at a particular point in time the quality of the pavement structure is relatively bad (trend I), the necessary reconstruction becomes more costly. Simple and more cost-effective measures (e.g., application of a single strengthening layer of pavement) are possible where at a particular point in

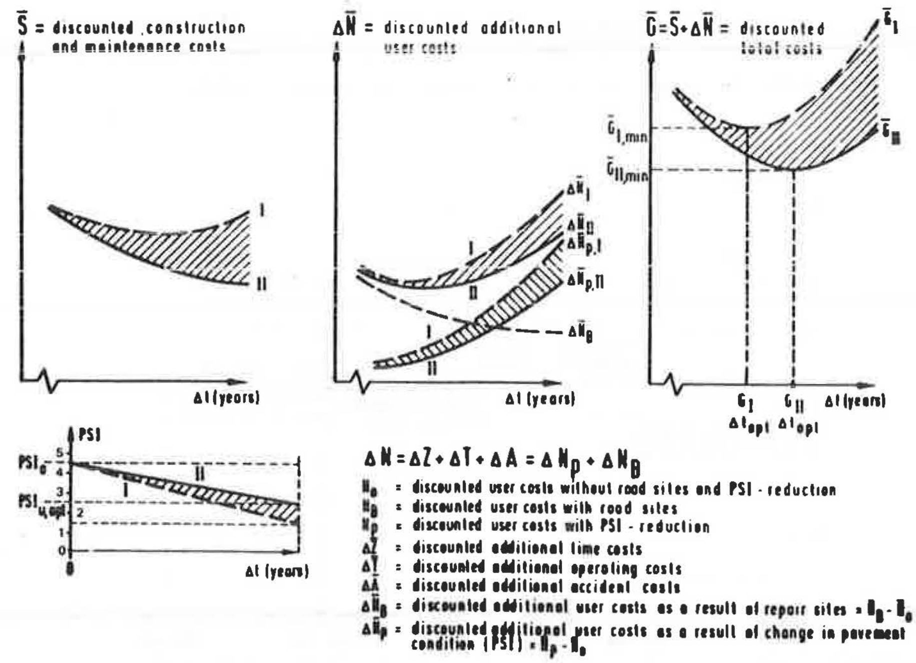


FIGURE 13 Fundamental correlations between discounted costs and intervals between, $\Delta t$, of maintenance measures.

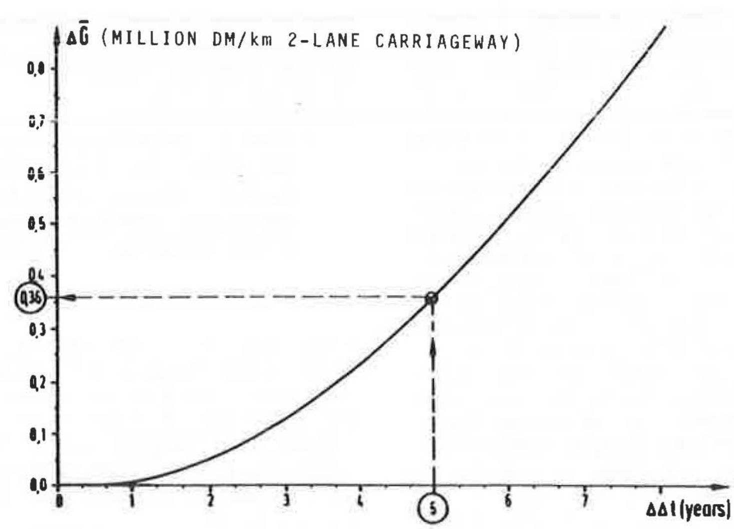


FIGURE 14 Additional discounted total costs, $\Delta\bar{G}$ (million DM/km), when optimum maintenance moment, $\Delta t_{opt}$, will be exceeded by $\Delta\Delta t$ years [an example for a two-lane highway with flexible pavement for high traffic volume (type I construction)].

time of reconstruction the quality of the pavement structure is still relatively good (trend II).

The agency costs will vary within the zone of the cross-hatched lines in Figure 13, according to the condition of the pavement at the point of time of renewal, as a function of the maintenance interval, $\Delta t$. Additional costs for the road users, $\Delta\bar{N}$, relative to the initial pavement condition (zero stage for planning, 0) arise from deterioration of the pavement with time ($\Delta\bar{N}_P$), and at maintenance sites where traffic delays occur ($\Delta\bar{N}_B$). The following elements comprise $\Delta\bar{N}$:

- Additional time costs, $\Delta\bar{Z}$;
- Additional operating costs, $\Delta\bar{T}$; and
- Additional accident costs, $\Delta\bar{A}$.

The diagram in the center of Figure 13 shows the additional user costs, $\Delta\bar{N}$, for trends I and II as a function of $\Delta t$. Furthermore, the diagram shows $\Delta\bar{N}_P$ (discounted additional user costs as a result of changes in quality) and $\Delta\bar{N}_B$ (discounted additional user costs resulting from delay of traffic at repair sites).

The diagram on the right shows the sum of agency and user costs for both serviceability trends I and II. A definite optimal point in time exists ($\Delta t_{opt}$) for performing road maintenance, depending on the trend for which the discounted total cost reaches a minimum. If the time chosen for rehabilitation is greater or less than the optimum ($\Delta t_{opt}$) then additional costs will be included in the total economic costs. Figure 14 shows an example of the extent of the additional discounted cost, $\Delta\bar{G}$, (in millions of DM per km of highway), subject to certain assumptions that are not discussed here. If the time of rehabilitation on the road network of the Federal Republic of Germany (which comprises approximately 160 000 km) should be changed by more than approximately $\Delta\Delta t = 5$ years against the optimum ($\Delta t_{opt}$), the loss in real terms of public expenditure would be on the order of 6 billion DM.

## CONCLUDING REMARKS

An attempt has been made to show in this contribution that a useful, practical instrument for both the establishment of financial needs and for the optimization of decisions for road rehabilitation has been developed in the Federal Republic of Germany. Because of the limited time, only a brief sketch of the subject could be presented. However, it is hoped that this discussion has provided at least an overall impression of available decision-making techniques and encouraged further interest in them.

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# Calculating a Zero-Based Maintenance Budget and Allocating Budgeted Resources by Using Objective Levels of Service and Performance Measures

**KARL KAMPE, JOHN CARR, and MARTIN WOY**

ABSTRACT

A new approach to the estimation of labor resource needs being developed by the California Department of Transportation to be used in budgeting is described. Seven calculation methods are employed to estimate labor resource needs for the entire maintenance program: historic projection, frequency calculation, condition evaluation, organization plan, training plan, proration, and capital project scheduling plan. Extensive research and engineering and statistical analyses are employed to develop the formulas and factors that correlate workload and labor resources by considering geographic variations due to station locations and staffing patterns and labor intensity variations by work type. The research and analysis rely heavily on information from the department's maintenance management system, which has been in operation more than 10 years. Another primary feature of this process is the definition of quantified levels of service for all field maintenance activities. These will be used in conjunction with the new calculation methods to relate staffing needs to variable levels of service. Top management decision makers will be able to make budget recommendations with a clear understanding of what they can buy and what they must forego if staffing is increased or decreased incremen-