MEDITER, A Model for Assessment of Rehabilitation Delay Cost in ERASME

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An expert system was developed to assess maintenance delay opportunity. This project relied on previous works in the field of pavement condition prediction, particularly those of the Highway Design and Maintenance Model. MEDITER is a model that mixes theoretical and experimental results. It is integrated into the ERASME project, the aim of which was to build a multiexpert system for pavement rehabilitation. An application of MEDITER to an actual example is presented, and conclusions are drawn.

Under funding constraints, pavement managers are interested in delaying needed rehabilitation on some network sections. However, no tool is available to enable pavement managers to assess pavement rehabilitation delay cost. Such cost is linked to

- Curative maintenance before actual rehabilitation, and
- Rehabilitation cost increase when delayed.

Although some theoretical works and experimental results have been published, no explicit information is available in France for predicting future pavement conditions without rehabilitation.

The research objectives were to

1. Elicit knowledge in the field of pavement condition prediction using results from the Highway Design and Maintenance (HDM) Model concepts (*1*), mechanistic rational analysis, and experimental results, particularly those given by the Laboratoire Central des Ponts et Chaussées (LCPC, France) Circular Test Track (CTT) (*2*);
2. Create a model for rehabilitation delay cost; and
3. Encode elicited knowledge into an expert system integrated in ERASME (*3*) architecture.

STATE OF THE ART

Many flexible pavement distress prediction models exist in the world, most of them in the United States.

Empirical Models

The AASHTO model was developed from the AASHO Road Test and incorporated into the AASHTO Interim Guide (*4*). This model is based on empirical observations and provides the predicted loss of serviceability, which is closely related to roughness, over a given range of values.

Large empirical studies conducted in Kenya and Brazil led to the HDM Model, which is probably the most comprehensive model at the present time, because it yields prediction of

- Cracking with initiation and progression phases, during which the cracking increases in extent and severity. Initiation and progression are predicted in two categories, all cracking (width not less than 1 mm) and wide cracking (spalled cracks).
- Rutting with mean rut depth and standard deviation.
- Ravelling initiation and progression.
- Potholing initiation and progression.
- Roughness progression.

HDM 3 Concepts

The growth of the cracking area of a given severity is a bell-shaped function with respect to time. As bell-shaped functions are awkward for modeling purposes, a cumulative total is defined, which represents the sum of all cracking areas of a severity not less than a given class of severity. The extent of cracking increases monotonically and presents a sigmoidal shape. The model takes into account uncertainty in the predictions because of variability of structural properties, drainage characteristics, construction quality, etc., over nearly homogeneous sections of pavement. The model automatically divides each section into three subsections identified as weak, medium, and strong to yield, for example, the ages at which the cracking of the three subsections (representing early, medium, and late failures) are expected.

Probabilistic Model

An original approach, developed by the Arizona Department of Transportation (*5*), takes into account the probabilistic aspect of road deterioration. This approach is derived from an Arizona data base that describes roughness and cracking progression. This process is Markovian and annually recursive, predicting indicator changes in 1 year as functions of previous values and environmental factors.

Mixing Empirical and Mechanistic Approaches

Mechanistic or theoretical methods based on the mechanical properties of materials and structural analysis of the pavement are invaluable for identifying the key variables and appropriate functional forms of distress evolution. When calibrated and validated to real conditions, the quality of predictions obtained by these methods appears better than that given by purely empirical methods.

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HDM 3 and VESYS (*6*) mix empirical and mechanistic approaches. VESYS is an FHWA structural subsystem that has been used by various agencies and universities throughout the United States. VESYS computes stresses, strains, deflection, rutting, cracking damage, and roughness.

State of the Art in France

There is one currently nonvalidated distress prediction model in France which consists of empirical laws concerning changes in deterioration, derived from the analysis of a data bank. This model was implemented in a pavement management system (PMS) for road networks (*7*). Normal cumulative distribution functions were established that yield percentages of pavements for several distress levels. Investigation continues according to these empirical laws.

Some prediction capability is available as follows:

1. The CTT has provided evolution curves of cracking and rutting on different pavement types. Cracking fatigue results are in accordance with those expected by elastic theory (*8*).
2. The unbound granular material and soil behavior study and the associated creation of a numerical analysis model (*9*) using finite elements have enabled a nonlinear elastic modelization of unbound aggregate materials and soils to be derived from experimental laboratory tests on several such materials. Knowing certain behavior laws, the rutting of a flexible pavement versus cycle number at different depths of the pavement can be obtained. Low-cost devices are currently under development in France to assess behavior laws of field pavement materials.
3. A satisfactory connection has been obtained between pavement distress condition in terms of cracking and repairs and the theoretical risk derived from elastic and fatigue theory at a known cumulative traffic level on a test section of a highway network (*10*). The pavement test section had three layers of asphalt materials with a total thickness of 30 cm built on 40 cm of unbound, well-graded aggregate.

Knowledge for building a model such as MEDITER does exist.

MEDITER MODEL

MEDITER includes two functions:

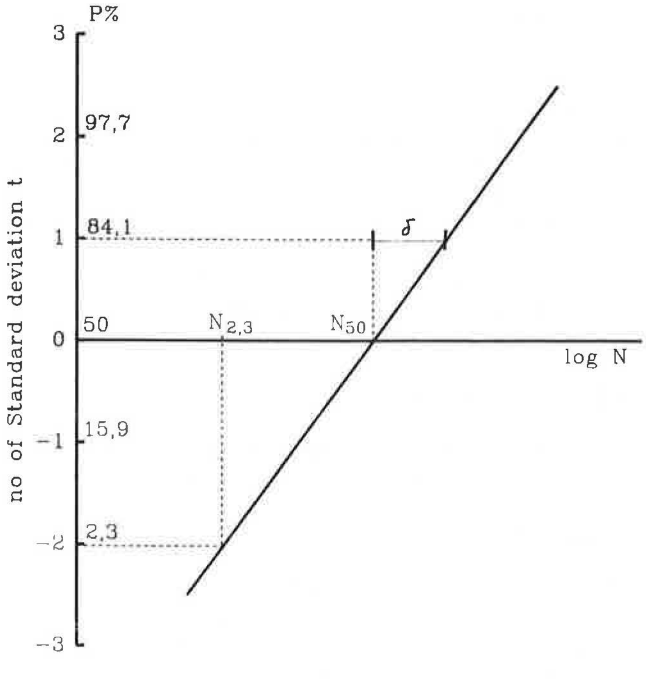
1. Forecasting evolution of key flexible pavement distress in the case of a rehabilitation or reconstruction delay, using the flexible pavement distress prediction (FPDP) model; and
2. Assessing maintenance cost increases caused by a rehabilitation or reconstruction delay (for which maintenance includes surface dressings, pothole patching, rehabilitation, and reconstruction).

In the same way as ERASME, MEDITER treats homogeneous sections whose significant parameters are sufficiently alike along their length.

FPDP Model

The FPDP model does not claim to improve knowledge, but to aggregate available knowledge. FPDP is based on seven ideas:

1. Mechanistic analysis of a flexible pavement relies on two main parameters, the horizontal tensile strain at the bottom of the bituminous surface layer and the vertical compressive strain at soil surface level;
2. Flexible pavements have two key distress types—cracking and rutting—which are related to the two previous parameters;
3. Homogeneity is an inadequate concept for pavement, so, as in the HDM model, the variability of homogeneous section concept is introduced;
4. Along the length of a section, distress evolution depends on the variability of pavement structure, layer thicknesses, asphalt and unbound materials characteristics, soil characteristics, environmental factors, and drainage characteristics;
5. In flexible pavement engineering, variability of deflection is a good parameter for tracking variability of pavement structure and soil characteristics. Homogeneous sections are divided into three subsections: weak, medium, and strong, associated with characteristic, medium, and low deflections, respectively.
6. Along one subsection, some variability still occurs and is dependent on asphalt mix fatigue law dispersion and environmental factors. Variability on each subsection is small compared with section variability. To assess variability, two evolution curves, namely optimistic and pessimistic, of the whole section were drawn up and calibrated on several field experiments; and
7. The two key distresses are depicted by two characteristics: extent expressed in percentage of length or surface and severity related to cumulative length of cracks by surface unit (m/m^2) for cracking, and rut depth (mm) fur rutting.



Probability corresponding to number of standard deviation t is also figured on Y-axis
Value of standard deviation δ is read directly on the graph

FIGURE 1 Cumulative normal distribution in a plane ($x = \log N$, $y = t$) and correspondence between t and probability P.

Three prediction submodels have been created which forecast cracking, rutting, and deflection evolution.

Cracking Model

The following steps are performed:

1. Three subsections are defined as weak, medium, and strong, associated with a characteristic, medium, and low deflections, respectively;
2. For each subsection, a mechanistic assessment is carried out by computing elastic strains and stresses with ALIZE (*8*), and by using the bituminous concrete fatigue relationship with cumulative numbers of axle loads that leads to a 50 percent risk of cracking, to obtain three characteristic parameters, $N_{50}^{\text{weak-subsection}}$, $N_{50}^{\text{medium-subsection}}$, and $N_{50}^{\text{strong-subsection}}$.
3. It is asssumed that the log N distribution on the entire section is a normal statistical distribution defined by

$$N_{2}^{\text{section}} = N_{50}^{\text{weak-subsection}}$$

$$N_{50}^{\text{section}} = N_{50}^{\text{medium-subsection}}$$

$$N_{98}^{\text{section}} = N_{50}^{\text{strong-subsection}}$$

where N_2, N_{50}, and N_{98} stand for cumulative axle loads that lead to 2, 50, and 98 percent cracking risk, respectively, on the homogeneous section. (Cracking variability on each subsection is ignored at this step.)

4. The standard deviation δ of that distribution is (see Figure 1)

$$\delta_{\text{cracking}} = \tfrac{1}{2} (\log N_{50} - \log N_2) \qquad (1)$$

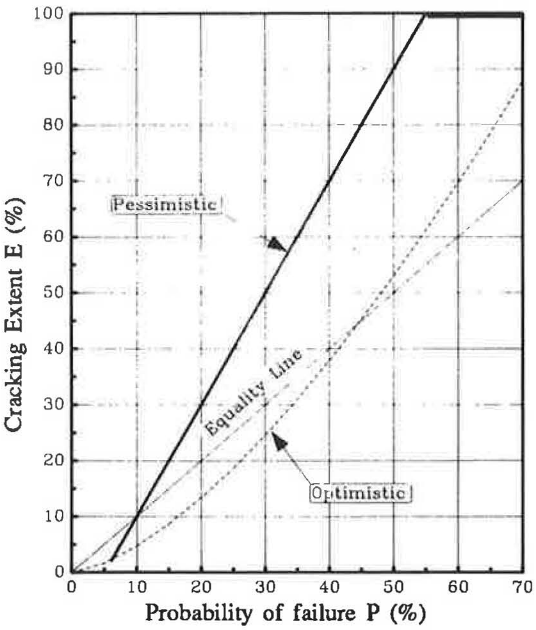


FIGURE 2 Relation between failure probability *P* and cracking extent *E*.

or, more generally,

$$\log N' = \log N + \delta_{\text{cracking}}(t' - t) \qquad (2)$$

where t and t' are the fractiles of the log normal distribution law associated with given probabilities of failure P and P' at N and N' cycle numbers, respectively.

5. It is assumed that extent (E) of cracking and probability (P) of failure are strongly correlated (see Figure 2). Experimental results on a highway section (*10*) can be described by

$$E = 2P - 10 \qquad (3)$$

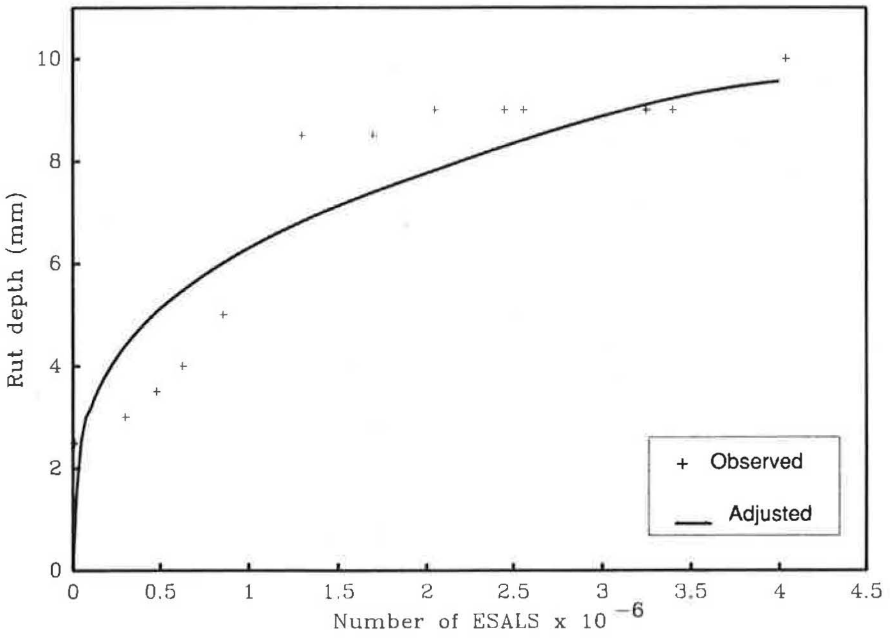


FIGURE 3 Example of rut depth evolution versus *N* on one cross section (LCPC CTT results).

and the results obtained on the CTT are

$$E = 0.15P^{1.5} \tag{4}$$

These two results define an area of expected cracking as

$$0.15P^{1.5} < E < \max (2P - 10;\ 0.15P^{1.5}),\ \text{with } E_{\max} = 100 \tag{5}$$

This step allows variability at the whole section level, previously ignored on each subsection, to be taken into account.

6. This area is associated with the extent of all cracking; i.e., cracks that are at least perceptible (0.1 to 0.2 m/m^2).

7. Other areas can be defined for severe cracking and potholes. It is assumed that, for a given extent

$$N_{\text{severe-cracking}} = 2.5N_{\text{perceptible-cracking}} \tag{6}$$

$$N_{\text{pothole}} = 3.5N_{\text{perceptible-cracking}} \tag{7}$$

where $N_{\text{perceptible-cracking}}$, $N_{\text{severe-cracking}}$, N_{pothole} stand for cumulative axle loads relative to perceptible cracks, severe cracks, and potholes, respectively. Equation 6 has been calibrated with CTT results. The mean size of severe cracking pattern is about 20 cm. It is assumed that extent E of severe cracking and potholing is related to the probability of emergence P by Equation 5. Potholing extent $E_{\text{potholing}}$ is computed as

$$E_{\text{potholing}} = \text{percent of 100-m lengths of section containing at least one pothole.} \tag{8}$$

Rutting Model

Rutting forecasting is a difficult engineering task; behavior laws of unbound materials and soils cannot be assessed at a low cost (*9*). Experimental results from CTT (*3,11*) have shown that rut depth increases as $N^{0.4}$ (see Figure 3) (N is the cumulative number of 13-tonne single-axle loads). At a given cumulative N, the log RD (rut depth) distribution may be adjusted to a normal statistical distribution (see Figure 4), from which log N also presents a normal statistical distribution for a given rut depth.

To take into account pavement structure and soil quality, it was assumed that RD increases as $(N/N_{allowable})^{0.3}$ $N_{\text{allowable}}$ is obtained by using a Dormond-like rule applied to the vertical compressive strain on soil bearing the pavement, in such a way that deflection has the mean value d_m of the deflection distribution. Furthermore, it is assumed that for $N = N_{\text{allowable}}$, RD is between 20 and 30 mm when its extent is 50 percent.

Therefore,

$$20(N/N_{\text{all}})^{0.3}\ 10^{-0.3t\delta_{\text{rutting}}} < RD < 30\ (N/N_{\text{all}})^{0.3}\ 10^{-0.3t\delta_{\text{rutting}}} \tag{9}$$

where δ_{rutting} is the log N dispersion for a given rut depth and t is the fractile of the log N distribution associated with probability P of having rut depth RD. P is then assumed to be the extent of rutting of which the depth is RD. Equation 9 gives pessimistic and optimistic evolution curves of rutting extent versus N, for given RD.

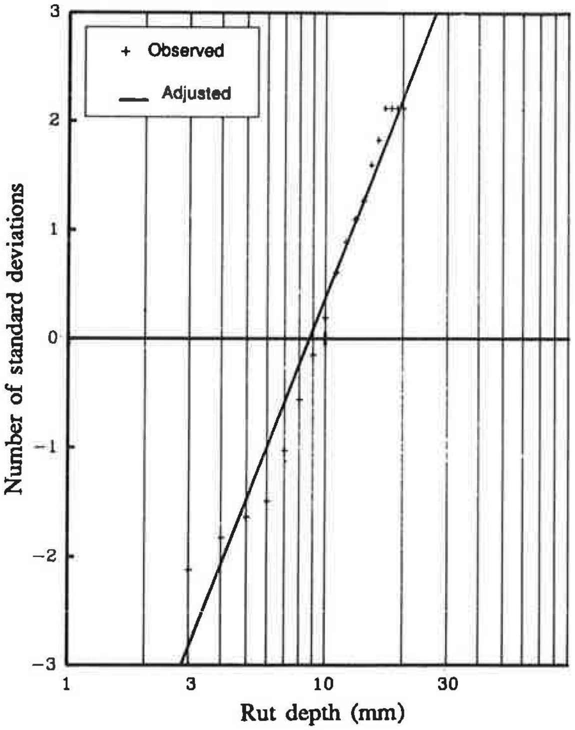


FIGURE 4 Example of rutting dispersion along length for 4 × 10^6 repetitions (LCPC CTT results).

To calculate δ_{rutting}, similar steps were performed to those concerning cracks, by calculating for weak and medium subsections the cumulative number of axle loads that are assumed to lead to 2 and 50 percent occurrence probability, respectively, of at least 20 to 30 mm rut depth. Thus,

$$\delta_{\text{rutting}} = \tfrac{1}{2}\ (\log N_{50} - \log N_2) \tag{10}$$

where N_{50} is the same as $N_{\text{allowable}}$ in Equation 9.

Deflection Model

Throughout pavement life, deflection has three ranges. For $N < N_{\text{allowable-for-deflection}}$, deflection is constant. Then, for $N_{\text{allowable-for-deflection}} < N < N_{\text{disallowable-for-deflection}}$ deflection may increase about 10 percent. Finally, for $N_{\text{disallowable-for-deflection}} < N$, deflection increase can be strong, up to 100 percent, and random. In these inequalities, $N_{\text{allowable-for-deflection}}$ and $N_{\text{disallowable-for-deflection}}$ are two MEDITER-calculated cumulative numbers of axle loads.

In flexible pavement engineering, deflection evolution primarily depends on surface layer permeability, which is the ability of water to pass through surface layers and to increase soil moisture content. This ability being related to the extent and severity of cracking implies that the two previous terms are calculated as

$$N_{\text{allowable-for-deflection}} = N^{\text{weak-section}}_{\text{perceptible-cracking}} \tag{11}$$

$$N_{\text{disallowable-for-deflection}} = N^{\text{medium-section}}_{\text{severe-cracking}} \tag{12}$$

Deflection stays constant until a 0.5 percent extent of perceptible cracking, and then increases to 10 percent when severe cracking extent reaches 53 to 90 percent.

Conclusions for FPDP Model

Pavement evolution is broken down into three simpler subelements, and can be summarized by cracking, rutting and deflection evolution. An FPDP model constitutes a simple modelization of complex interactions in which, among other relationships, cracking increases the permeability of the surface layer, affects the amount of rutting, cracking of the surface layer, and the permeability of the surface layer determines the amount of rutting.

Although the cracking and deflection prediction models seem well developed, some work needs to be done on rutting prediction.

Maintenance Delay Assessment

Because of funding constraints, pavement managers sometimes delay rehabilitation work. MEDITER will help them to assess rehabilitation delay costs, which can be broken down into four parts:

1. User costs linked to road deterioration (which are not evaluated by MEDITER, a section level tool).
2. Patching costs on severely cracked areas and potholes. Patching does not prevent an increase in cracking but it delays moisturizing of structure pavement and soil. It was assumed that patching is carried out each year on areas that become severely cracked the previous year, and patching durability decreases from 5 years for an average daily traffic (ADT) of less than 1,000 to 2 years for an ADT of more than 15,000.
3. Road shape correction costs caused by rutting. In France, it is estimated that for ruts greater than 25 to 30 mm user's comfort and security are put at risk and pavement resurfacing has to be carried out.
4. Rehabilitation cost increases because of loss of strength of pavement structure. This increase is directly linked to increase in deflection.

INTEGRATION OF MEDITER IN ERASME

Diagnosis, Design, and Prediction

Evaluation of a pavement and development of feasible rehabilitation alternatives are performed according to the following steps:

1. Evaluation of present condition,
2. Prediction of future condition without rehabilitation,
3. Rehabilitation designs,
4. Prediction of future condition on each design,
5. Cost analysis of each design, and
6. Physical testing as needed.

ERASME V8.0 performs Steps 1, 3, and 5. MEDITER integration will bring in Step 2.

Multiple Diagnoses

For some pavement problems, when the ERASME diagnosis expert system detects inconsistencies between several data, it proposes several concurrent diagnoses. Each of these diagnoses is associated with certain hypotheses; for example, mistakes in data.

For each obtained diagnosis, ERASME will perform Steps 2, 3, and 5. During Step 2, MEDITER will assess several rehabilitation delay opportunities associated with concurrent diagnoses.

EXAMPLE OF APPLICATION

Case Description

A 30-km section of RN 104, located in Ardèche, France, was surveyed in 1978, and rehabilitation was found to be needed. Four years later, rehabilitation work had still not been undertaken, so a new survey was carried out.

The pavement condition on a 1. 5-km homogeneous section was as follows:

Pavement Condition	*1978*	*1982*
Mean deflection (mm/100)	55	55
Characteristic deflection (mm/100)	100	100
All cracking (percent of area)	55	84
Severe cracking (percent of area)	8	22
Perceptible rut depth (percent of length)	63	70
Severe rut depth (percent of length)	0	0.5

Pavement structure was given as

1. 6-cm bituminous concrete layer dated 1969,
2. Old successive surface dressings,
3. 50-cm old granular subbase, and
4. Clay and coarse-gravel soil.

Its two-way ADT as found to be 3,400 with 5 percent truck traffic in 1969. Traffic growth was about 6 percent per year. By 1978, 3 × 10^5 ESALs (130 kN) by lane had been accumulated.

Predicted Performance Since 1969

Since RN 104 was rehabilitated in 1985, it was not possible to compare 1989 predicted and measured conditions. However, two measured conditions in 1978 and 1982 were used. As shown in Figures 5 and 6, predicted and measured values were closer for cracking than for rutting.

Rehabilitation Delay Cost

The 1985 rehabilitation consisted of an 8-cm bituminous concrete overlay, the cost of which was $70,000/km—the cost of bituminous concrete being about $50/ton (these costs are in 1979 dollars).

Patching From 1979 to 1985, cumulative predicted cost of patching on severe cracking ($10/m^2) was between $25,000/km and $50,000/km, i.e., $4,200/year-km to $8,400/year-km. Predicted potholes were between 0/km and 1/km in 1978,

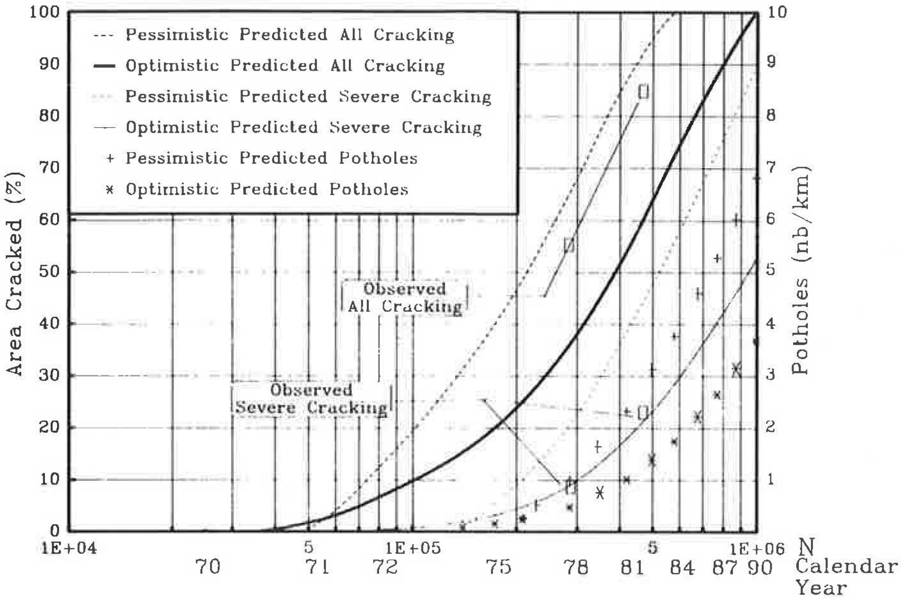


FIGURE 5 Observed and predicted cracking and potholes.

between 2/km and 4/km in 1984. Pothole patching is not expensive: from $10 to $20 for one pothole. However, they cannot be left because of user security.

Rutting Rutting was not a real problem on this road section because less than 1 percent of the section length presented a severe (about 30-mm) rut depth in 1982. Resurfacing cost was between $20/m and $40/m of rut, which is less than $400/km.

Rehabilitation Cost Increase Between 1978 and 1985, increase of deflection was less than 2 percent and had a negligible effect on rehabilitation cost.

To sum up, total discounted cost in 1979 value at 8 percent discount rate of 1985 rehabilitation plus interim cost for maintenance, leads to an estimation between $65,000/km and $86,000/km, compared with a $70,000/km cost for 1979 rehabilitation. Comparisons should have been made by adding maintenance costs subsequent to the 1979 rehabilitation, but on this new overlay distress over 6 years is negligible.

Of the total discounted cost, rehabilitation cost was $44,000 and interim maintenance between $21,000 and $42,000, or between half and total of the discounted rehabilitation cost (difference between higher and lower estimation results from prediction model). To avoid a decrease in user security because of potholes and rutting, and to avoid the risk of spending up to 20 percent more than the 1979 rehabilitation cost, it would

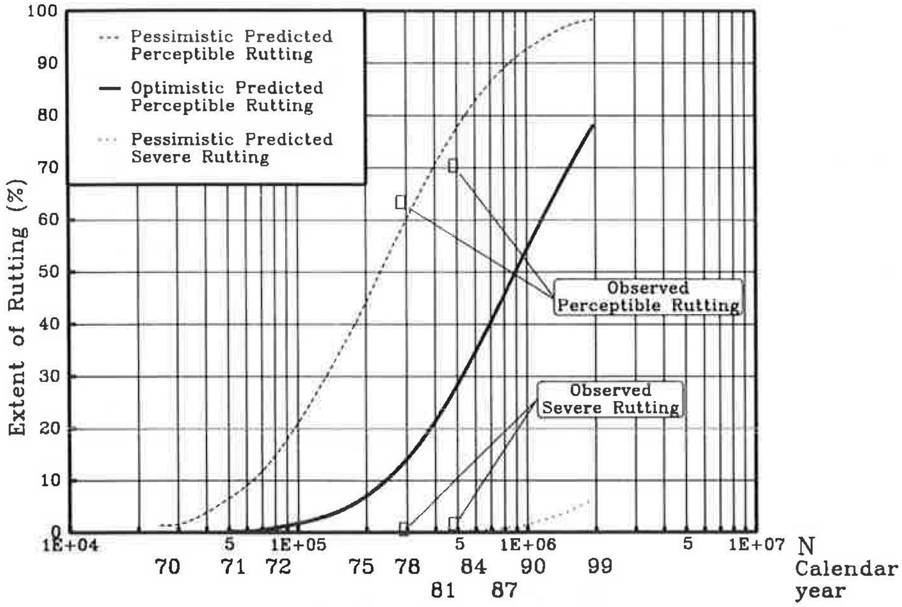


FIGURE 6 Observed and predicted rutting.

have been more advisable to carry out rehabilitation as early as 1979.

CONCLUSION

1. MEDITER is the first approach in France at designing a model for the assessment of rehabilitation delay opportunity. This model uses distress prediction laws built from theoretical and experimental results, and assesses interim routine maintenance costs and increases in rehabilitation work costs because of rehabilitation delay.

2. At present, MEDITER works only for flexible pavements, when the main distress is fatigue of the asphalt mix surface course and structural weakness. Surface dressing distress is not treated, nor is thermal cracking of asphalt mix. Bituminous and hydraulic bounded pavements will be studied in the future.

3. Calibration and validation are needed to improve the quality and reliability of MEDITER. In 1990, it will be implemented on validation sites with this aim in view.

4. User costs are not taken into account in economic comparisons, but serviceability takes place by means of trigger threshold for routine maintenance.

5. MEDITER operates at the section level, not at the network level, unlike a PMS. However, applied to several sections of a network, it could define a priority range among these sections, and thus might find a place in a PMS.

6. Hence, MEDITER constitutes a long-awaited tool, which will enable the asessment of rehabilitation delay consequences for pavement managers, who are so often subjected to funding constraints.

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