French Strategy for Preventive Road Maintenance: Why and How?

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The French national road network, which is 28 000 km long, is subject to heavy traffic, sometimes under difficult climatic conditions. An ambitious policy for rehabilitating this network has been in effect since 1969, and since 1972 a preventive maintenance strategy has been applied. In this paper are described the reasons that led to that choice of strategy, and figures drawn from 15 years of experience are supplied. The preventive maintenance system includes a rigorous follow-up study of pavement behavior based on data obtained with powerful measuring devices. The Road Data Bank collects and processes the data, and information is made available in a technical guide to ensure coherent implementation of the selected strategy.

The preventive maintenance system used in France provides a very good service level, regardless of climatic conditions. It is important that the capital investment that this road network represents be protected by maintaining the network to meet users' requirements. The financial effort agreed to is small compared with the savings it produces—particularly in terms of vehicle operating costs and, to a certain extent, journey times. The documents used to prepare this paper can be made available to all persons interested in the subject.

WHY?

French Main Roads—A Dense and Busy Network

France has a network of 28 000 km of national roads across her 550 000 km^2 (212,300 mi^2). These roads accommodate an average of 7,800 vehicles per day of which 13 percent are heavy goods vehicles (HGVs); in this context an HGV is a vehicle with a payload of 5 tons or more.

Renovation and Preventive Maintenance Policy

In 1969 France began reconditioning the national road network at an average rate of 1000 km per year. From a technical point of view, this program (known as "coordinated reinforcing") consisted of putting down a road base and a wearing course.

So far 2.2 billion francs (about $350 million) has been spent on coordinated reinforcing, and about 6000 km remain to be treated.

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Beginning in 1972 (3 years after the start of the program), a preventive maintenance policy was adopted. This policy represents the second step, fully in stride with the first one, that consists of the complete renovation of the network to adapt its structure to both traffic and climate.

A volunteerist policy provided for ambitious new targets. Three closely linked objectives are associated with this preventive maintenance policy:

- To provide the country with a consistent traffic flow level, regardless of climatic conditions;
- To provide, at all times, a consistent and unchanging quality of service to users, bearing in mind users' ever growing safety and comfort requirements; and
- To adapt road structures to foreseeable traffic conditions.

Roads awaiting rehabilitation are subject to an upgrading maintenance policy the aim of which is simply to limit degradation while ensuring necessary repairs to maintain traffic flow.

It was not easy to get the preventive maintenance policy accepted as reasonable because maintenance of rehabilitated roads costs about twice as much as maintenance of the same roads before rehabilitation. Rehabilitation had adapted pavements to the new requirements, especially by making them frost resistant. The higher maintenance costs were therefore consistent with the objective of maintaining capital investment value and with the desire to avoid damage by severe winters or heavy vehicles. Preventive maintenance should prevent ever having to invest in a second rehabilitation program.

Those responsible for roads, as well as locally elected officers, who could have had the impression that money was being spent on roads in seemingly good condition and that nonrehabilitated roads were being left to deteriorate, had to be convinced. The basic principle of preventive maintenance implies spending money before the quality of pavements deteriorates seriously or irrevocably, and so the concept of carrying out work on apparently good pavements must be accepted. Moreover, in the early 1970s the temptation to divide funds and maintenance more "equitably" between rehabilitated and nonrehabilitated roads was great.

If the preventive maintenance policy finally prevailed it was because it was the logical extension of a credible combined rehabilitation policy; users of nonrehabilitated roads simply had to be patient, and, in any case, the Directorate

of Roads aimed to complete reinforcement of the 28 000 km of national roads by the early 1980s. Despite the considerable time taken for combined rehabilitation, the target was maintained.

STRATEGIES

There is no single strategy for renovating and maintaining a road network. Various strategies can be imagined for upgrading and maintaining underdesigned or damaged pavements such as those in France in the late 1960s. The following four strategies have undergone detailed comparative studies.

Strategy 1: Localized Repairs Without Structural Strengthening

This strategy consists of allowing deterioration of the pavement to continue while searching, whenever possible, to avoid acceleration (punctual repair is carried out on deteriorations when they appear and surface dressing may be done for protection against water infiltration).

This is a strategy of submission, not direction. Most often it is the result of abusive budgetary restrictions, and it is no doubt an exaggeration to consider it a real strategy.

This strategy provides a low level of service; the evenness obtained is mediocre and ephemeral. It gives no improvement to the structure, and the probability of blocking traffic during a thaw is in no way reduced.

This strategy is rather restrictive for the manager because it requires uninterrupted surveillance of the network along with rapid, frequent, and nonprogrammable intervention because potholes or other deteriorations of similar nature must be repaired as soon as they appear.

A large work force and adapted equipment are required, and it is difficult to optimize all of these factors. In reality, this strategy should be applied only to a very secondary network with little traffic.

Strategy 2: Progressive Redressing

This strategy consists of applying relatively thick asphaltic concrete wearing courses (approximately 10 cm) at regular intervals (about 5 years in cases of average traffic) with bank supports and improvement of the drainage system if necessary.

Localized interventions might still be necessary in order to repair deteriorations that might follow a severe winter.

This strategy has several drawbacks:

- The laminated structure of the pavement prevents adequate behavior of the assembly;
- The structure remains underdesigned and therefore fragile; during a severe winter it may be necessary to restrict heavy-vehicle traffic during thaws; and
- Repeated interventions on traveled carriageways cause considerable nuisance for users.

This strategy leads to the exclusive use of asphaltic materials, and asphalt produced from petroleum is costly.

Nevertheless, there are some advantages:

- The initial investment is relatively moderate, which, at a given budgetary level, makes possible more rapid renewal of the network and good homogeneity;
- Except during severe winters, the level of service remains adequate; and
- The techniques used are highly flexible in both program and execution.

This type of strategy therefore appears to be well adapted for networks with moderate or average traffic in areas where the climate is generally not severe.

Strategy 3: Strengthening Followed by Preventive Maintenance

This strategy requires a large initial investment for a pavement design thickness that will provide a service life similar to that which is given to a new pavement vis-à-vis both traffic and frost. This is the strategy that has been applied to the national road network since 1969. It should be stressed that a quarter of this network carries more than 750 HGVs a day.

To maintain the capital investment, this strategy envisages follow-up structural strengthening so that the surface qualities (evenness, roughness, waterproofing) remain at a high level and that, at the same time, compensation is made for the accumulated fatigue of the road base.

Maintenance work is therefore mainly surface dressing or laying an asphalt wearing course of variable thickness. It is thus possible, if maintenance interventions are carried out in time, to give the pavement an almost infinite service life.

However, this strategy requires a very high initial investment, and it is illusory to envisage the general strengthening of an entire network within a short time; the manager is obliged to concentrate the investment effort on those parts of the network that are considered top priority, and consequently he must delay intervention on the remainder of the network (i.e., adopt Strategy 1, a strictly curative strategy, for the latter network).

Any continuous and excessive budgetary restrictions can undermine the overall credibility of such a strategy because they delay the renovation of a part of the network that is deteriorating acceleratingly.

Strategy 4: Strengthening Followed by Curative Maintenance

This strategy is a combination of Strategies 1 and 3. It consists of strengthening the existing pavement (as in Strategy 3) and then ensuring maintenance by patching and dressing (as in Strategy 1). When a break in the pavement occurs, new strengthening is required and the cycle is repeated.

The level of service, good at the beginning, deteriorates in time (this is contrary to the user's wishes); it remains superior,

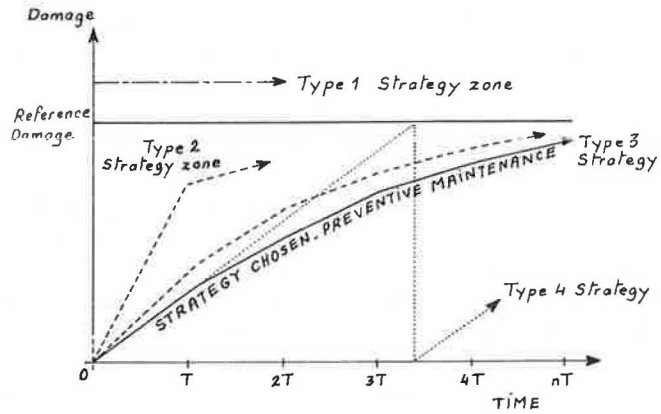

FIGURE 1 Fatigue damage by strategy.

however, to the level obtained with Strategy 1, particularly at the beginning of the cycle.

As is the case with Strategy 3, a very high initial investment is necessary. The present strategy is nevertheless still more sensitive to budgetary fluctuations because an extreme limit is awaited before strengthening action is taken.

Indeed, everything takes place as if a massive investment were made and the capital were left to progressively consume itself; it is then reconstituted as the end of the term.

Recapitulation and Conclusions

Figure 1 shows the evolution in time of fatigue damage sustained by a pavement. For this analysis, "pure" strategies are used; however, various combinations can be found in reality, particularly after a delay in the execution of certain maintenance operations.

The first horizontal line represents reference damage, that is, the accumulated damage sustained by the pavement at the end of its design life in the absence of all structural maintenance. Consequently, as long as the reference damage line has not been reached, fatigue breaking of the pavement should not occur.

The interval of time between two interventions (in the case of Strategies 2 and 3) is equal to T.

The relative position of the strategies studied can be described as follows:

- Strategy 1 is always found above the breaking threshold, which is to say that the capital of fatigue is consumed from the beginning.
- Strategy 3 is represented by a converging series (given an hypothesis of damage additivity), the curve of which is asymptotic at the reference damage line. This means that routine maintenance interventions (T, . . ., N T) confer a practically infinite service life on the pavement.
- Strategy 4 implies that new strengthening will be done as soon as damage reaches the reference damage line.
- The area situated between the Strategy 3 curve and the reference damage line is the domain of Strategy 2, which is qualified as "progressive" in opposition to Strategy 3; the design thickness, which is initially much thinner (resulting in a larger damage curve slope), must later be compensated for by heavier maintenance interventions if the break threshold is not to be exceeded.

France has selected, for its national roads, a rehabilitation strategy followed by preventive maintenance to provide all users with a high level of service everywhere and under all climatic conditions (this is essential). After this was decided upon, large investments were agreed to as well.

HOW?

Regardless of its organization, a system of road maintenance management must

- Gather all information on the condition of the pavement;
- Define the work requirements and their classification in priority order; and
- Provide the engineers with a wide range of well-adapted, well-known, and reliable techniques.

The first task that people in charge of maintenance must assume is to appraise the road sections under their charge. For this, they have at their disposal data, measured or observed, that they must interpret and examine to determine rules for action. Two approaches are possible: (a) development and use of an overall indicator and (b) "serviceability index" or a parameter-by-parameter analysis.

Analysis of Parameters

Since 1972 present serviceability index (PSI) methods have been found to lack the qualities required of an ideal system for selecting stretches of road to be maintained in priority order. A parameter-based approach allows the required selectivity to be attained and, at the same time, takes advantage of modern auscultation methods and leaves the way open to future progress. This approach consists of fixing warning and intervention thresholds for each parameter (bearing capacity,

evenness, skid resistance, surface deterioration, etc.) based on foreseeable consequences such as safety and comfort of users and the structure itself (wearing course regularity, conservation of the structure, etc.).

Technical Guide to Preventive Maintenance

The *Technical Guide to Preventive Maintenance*, which was published in 1979 and is used today in all maintenance departments, is based on this concept. It should be noted that this guide has been in continuous use for nearly a decade by 1,300 subdivisions of a hundred or so public works district directorates. Even though true "pavement management systems" are now available in France and include the laws of deterioration evolution for pavements, the wide use and value of this guide should be stressed. It is the tool that allows coherent implementation of the chosen strategy.

This guide, designed for prime contractors, was written to answer three key questions:

- When and where should maintenance be done?
- What job is to be carried out?
- What is the degree of urgency of the proposed work?

The answers are not simple and the proposed approach, although constituting a remarkable advance in a domain that has been neglected and devalued, offers only provisional solutions, which are, however, precious to decision makers.

To define maintenance requirements, the guide retains three successive approaches, which are relatively independent of each other and cover the main maintenance objectives:

- Conserve and adapt the structure;
- Conserve general safety and comfort; and
- Conserve the intrinsic surficial qualities of the pavements.

For each of these objectives, the pavement condition is characterized by a series of quantified condition indicators: deflection, evenness, roughness, and apparent strains (the list of the indicators obviously differs with respect to the objective considered). These indicators are generally accompanied by two or three degrees of gravity in comparison with reference values.

If he knows the value of the condition indicators, and the various data on the structure or previous works as well as the road environment, the engineer in charge of maintenance can diagnose pavement conditions. In practice, he marks the sections that raise problems (this is the summary diagnosis) and then searches for the cause of the detected faults and attempts to predict their evolution (this is the detailed diagnosis). When the diagnosis has been made, homogeneous sections are defined from the point of view of their condition (identical indicators and degrees of gravity) under each of the three approaches mentioned previously.

Because of the intervention thresholds provided by the maintenance regulations, it is now possible to define elementary work sections. These thresholds constitute "quality standards" that link the quantitative condition indicators to the various possible maintenance jobs.

The final works program is obtained by making a synthesis of the defined elementary works. The works retained are then classified according to their priority by means of a system of notation that is based on the nature and gravity of the detected defects. In certain cases, a laboratory study is necessary to define the content of the works.

Table 1 gives the Technical Guide method for the "conserving the structure" objective in the case of untreated subbases. It gives warning and intervention threshold values and

TABLE 1 WARNING AND INTERVENTION THRESHOLDS

Condition Indicator	Parameter	Degree of Gravity	
		Level 2	Level 1
Deflection	Deflection to $1/100$ mm depending on traffic		
	T0	35–50	Values greater than Level 2 maximum
	T1	50–75	
	T2	75–100	
	T3	100–150	
Structural Deterioration			
Roadside defects (subsidence, ridges)	Percentage of pavement length affected	5%–10%	Values greater than Level 2 maximum
Depressions and potholes (appearing or filled)	No. per 200-m section	2–4	Values greater than Level 2 maximum
Large-scale rutting	Average depth	15–20 mm	
	Percentage of length rutted	> 30%	20 mm over more than 30% of length
Crazing	Percentage of surface crazed	2%–5%	Values greater than Level 2 maximum
Longitudinal cracks in wheelpaths	Percentage of length cracked	5%–10%	Values greater than Level 2 maximum
Roughness	Irregular roughness	Considerable reduction in value (2 points minimum) between two successive measurements may indicate structural deterioration	

TABLE 2 DEFINITION AND CLASSIFICATION OF WORKS BY PRIORITY (*Guide technique de l'entretien préventif,* SETRA-LCPC, 1979)

	Deflection		
Structural Deterioration	Level 1	Level 2	Less Than Level 2
Structural deterioration			
Level 1	Priority 1	Priority 1	Priority 2
Level 2	Priority 1	Priority 2	Surveillance[a]
Likely to become generalized	Priority 2	Surveillance[a]	
Absent	Backup study[b]	Surveillance[a]	

[a] Special surveillance of the section and detailed inspections and additional measurements if required. Local repairs if necessary.
[b] To define the types of works to be planned and their urgency.

definition of the required works based on these thresholds. Classification of works by priority is given in Table 2.

Traffic Group T1 is calculated from the mean daily traffic of HGVs on the most used lane of the road. T0 corresponds to between 750 and 2,000 HGVs per day. T1 corresponds to between 300 and 750 HGVs per day. T2 corresponds to between 150 and 300 HGVs per day. T3 corresponds to between 50 and 150 HGVs per day.

If, on a road with an untreated subbase that has 600 HGVs per day (T1), there is a deflection of 70/100 mm (Degree of Gravity 2) and crazing of 6 percent of the pavement (Level 1 deterioration), then the necessary maintenance works are of Priority 1.

Maintenance Management System

The maintenance management system throughout the national network is based on strict surveillance of pavement behavior and condition. This follow-up is carried out by highly efficient auscultation equipment that complements a systematic, well-classified visual examination:

- The Lacroix deflectograph, developed in France, measures the deflection under a wheel loaded at 6.5 tons and traveling at a speed of 4 km/hr (there is a measuring point every 3.7 m). A new version of the apparatus, called "long chassis," allows detection of small variations in deflections on semirigid pavements.
- A section length analyzer, developed in France, allows simultaneous measurement of evenness in the two tire tracks at a speed of 72 km/hr. It makes it possible to obtain a technical mark for evenness between 0 and 10 for each 200-m section of road and for three ranges of wavelength.
- The SCRIM, developed in Great Britain, measures the transverse friction coefficient (one value every 20 m) at a speed of 60 km/hr with the aid of a measuring wheel inclined at 20 degrees with respect to the traffic direction. Since 1986 the SCRIM has been equipped with a Rugolaser that measures sand height, which is representative of macrorugosity.
- The GERPHO, which is a continuous-stream camera mounted on a vehicle, makes it possible to film surface deterioration at a speed of 50 km/hr. The films are examined in a semiautomatic manner with the aid of a reading board. The GERPHO is especially useful on heavily trafficked roads, mainly freeways, visual inspections of which are dangerous for personnel. It is particularly adapted to close follow-up inspection of concrete slabs, where the same types of deterioration are found along the entire route. The GERPHO could in no case take the place of a visual inspection on foot, but it can be used as a support tool for detecting sections that must be examined in more detail.

From the beginning, continuous rutting measurements have been unnecessary because in France the quality of bituminous mixes is such that widespread deterioration of this type does not occur, in spite of some very hot summers and the 13-ton legal axle weight.

The *Guide technique de l'entretien préventif* (Technical Guide to Preventive Maintenance) specifies the average frequency of passage of measurement devices, and each year the Roads Department establishes a program for the main road network.

The year after a new or strengthened pavement is placed in service, what is called a "zero point" is determined by allowing all of the apparatus to pass over the pavement.

Thereafter, roughness is measured every 2 years and evenness and deflection every 4 years. The GERPHO is not yet programmed systematically (except by most of the freeway management firms). If required, more frequent measurements are carried out on certain sections in case of either difficult diagnosis or rapid evolution.

Apparent deterioration of and strains on the pavement wearing course are marked during detailed visual inspections at least once a year and, if possible, twice a year. Carried out entirely or partly on foot, these inspections are written up in a report in which figure the deteriorations and strains, quantified and localized on the ground.

This method of pavement condition follow-up is one of the fundamental axes of the technical guide; the guide also includes a catalogue of deteriorations with definitions and pho-

tographs that make it possible for all of the services to use a common language and to greatly reduce possible differences in notation used by the various teams. Specific training is desirable for the agents responsible for visual inspections.

Road Data Bank

The Road Data Bank can be defined as an assembly of data-processing files that are coherent among themselves (particularly in terms of the location and definition of information), accessible to numerous users, able to be modified with respect to the evolution of their needs, and continuously updated.

A catalogue of information has been produced that specifies definitions and data collecting and updating methods for each type of data used. Seven types of data have been listed:

1. Basic information about nomenclature and administrative classification;
2. Geometric characteristics such as horizontal alignment, longitudinal section, and width;
3. General road equipment and appurtenances;
4. Road pavement structures and works including course types and thicknesses, binder types, and grading;
5. Road pavement auscultation data (skid resistance, evenness, deflection);
6. Traffic; and
7. Accidents.

Two devices for collecting data automatically have been developed:

- The Cameroute takes photographs every 10 m at a speed of 50 km/hr. It allows longitudinal and transverse distances to be measured and qualitative data on traffic signing, trees, barriers, and the like to be collected. The results are compiled manually.
- The Gyros is a gyroscopic device that allows bend radii and slopes to be calculated.

The data on the pavement structures and works are transcribed manually in letters on appropriate slips, according to a simple and rapid procedure.

It is also necessary to emphasize that the results obtained by the high-output measurement devices are integrated into the roads data bank.

One of the main products of the data bank is the Pavement Itinerary Sketch (PIS), which has been specially designed for use with the *Technical Guide to Preventive Maintenance.* The synthesis PIS shown in Figure 2 is an example of results of measurement by high-output devices and visual inspections (for a road section 10 km long) as well as information on the structure (nature and thickness of the layers, dates of measurements etc.). The PIS is used in establishing a pavement status diagnosis according to the Technical Guide.

Preventive Maintenance Strategy

The secondary network in France is made up of 347 000 km of district roads that carry an average of 1,200 vehicles per day. This average, however, hides considerable fluctuations.

On larger district roads, the local authorities generally operate under a policy inspired by that of the national network. On district roads with less traffic, curative maintenance, often using surface dressings and patching, is presently used.

In all cases, however, the strategies are based on systematic surveillance of the network. There is also a clear preference for a preventive maintenance policy for heavily trafficked motorways. The procedures used on both the privately and state operated motorways have their roots more or less in the Technical Guide.

RESULTS OF PREVENTIVE MAINTENANCE POLICY

Preventive maintenance provides a consistent, long-lasting high level of service for users. Since 1980, the *Technical Guide to Preventive Maintenance* has been applied to the national road networks in all French districts. By setting up "quality standards" and maintenance rules, the Guide has led to long-lasting roads and a consistent, quantified, high level of service.

Because the principle of this policy is to not intervene systematically or periodically, but according to an evaluation of real needs, the funds devoted to the maintenance of the national network can vary appreciably from region to region for a given year, or from year to year for a given region. In 1987, for example, the funds allocated per kilometer varied from 24,300 francs (about $4,050) in the Mediterranean region to 41,100 francs (about $6,850) in the South West region (the Paris region is not in this range because its highly urban nature leads to higher costs). Generally speaking, roads for which maintenance costs are lower are either those that have recently been rehabilitated or those that were rehabilitated a long time ago and have already received a thick maintenance layer. From year to year in a given region, preventive maintenance funds (per road kilometer) can vary by a factor of two and even three.

This clearly shows that merely allocating maintenance funds according to the mileage of roads would not ensure a consistent level of service.

From 1981 to 1987 the network covered by preventive maintenance has grown from 17 000 to 22 000 km (including state-operated motorways). During the same period the percentage of surfaces on which preventive maintenance works have been carried out has developed as follows:

Year	*Percentage*
1981	6.5
1982	6.6
1983	6.8
1984	5.9
1985	6.8
1986	8.2
1987	9.3

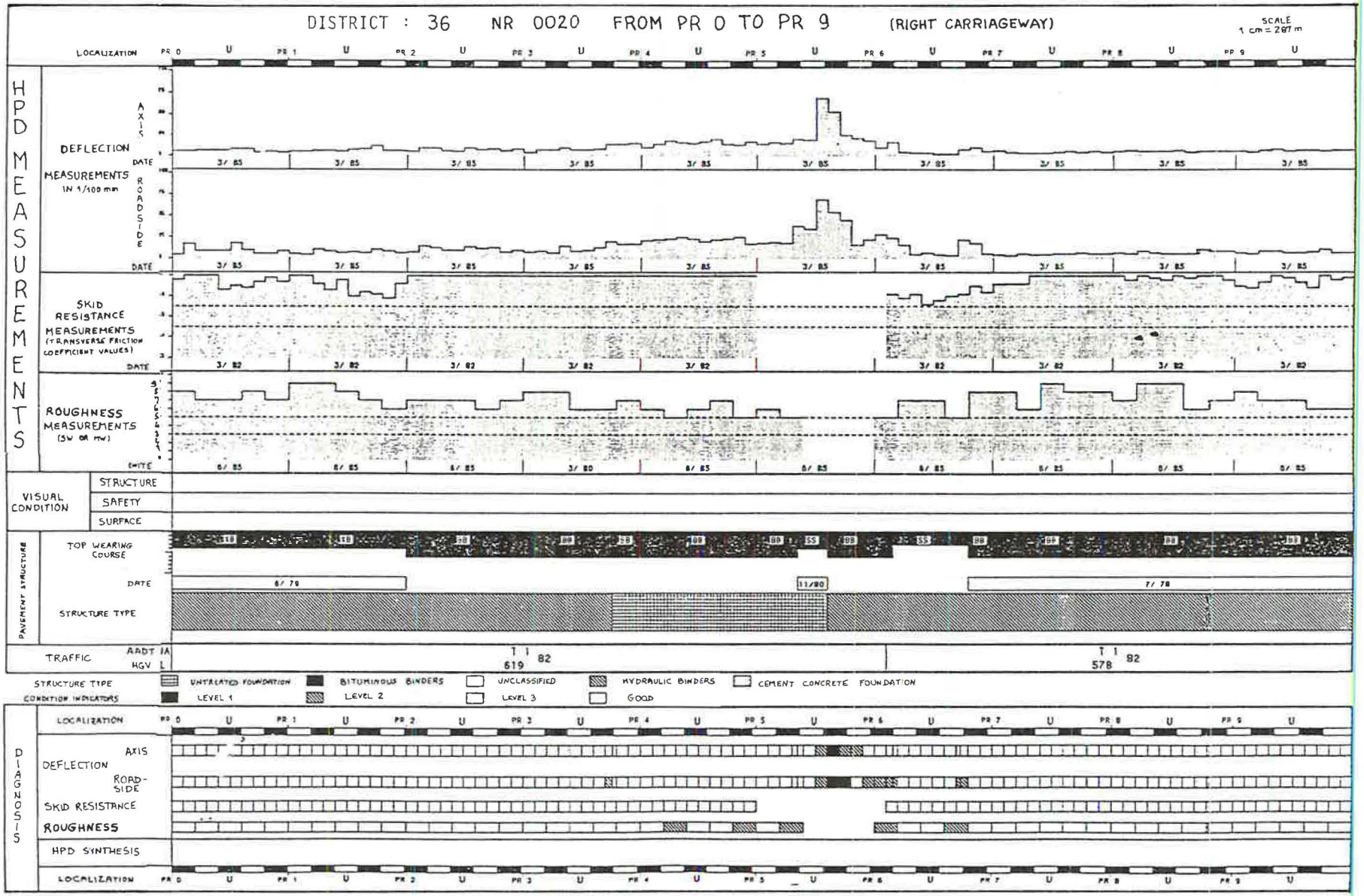

FIGURE 2 Example PIS; the diagnosis box contains a synthesis of comparisons with the Guide's threshold values.

This evolution was possible because the budget, which had gone up only slightly from 1982 to 1984, was considerably increased in 1986 and 1987.

This can also be explained by the evolution in the techniques used, more precisely by the use of techniques with a low cost–to–surface-treated ratio; more than 50 percent of the surfaces treated in 1987 were re-covered with a surface dressing or bituminous concrete less than 4 cm thick (compared with 33 percent in 1982). In 1987, 17 percent of surfaces treated received a layer of bituminous concrete more than 5 cm thick (compared with 33 percent in 1982).

Long-Term Funding

To be believable, a preventive maintenance policy requires adequate long-term funding. How the *Technical Guide to Preventive Maintenance* works and how it led to priority classification (Priority 1 or Priority 2) was described earlier. In practice, the overall demand volume for works, and consequently the necessary funding, can vary considerably upward, after hard winters, for example, or downward as a result of the use of "delaying" techniques such as surface dressings. Funding can also be modified by budgetary reallotments or limitations.

For these reasons funds devoted to preventive maintenance are not always sufficient; if the allocated funds are divided by the funds required to carry out the Priority 1 works [i.e., the most urgent ones ($\times$ 100)], it can be seen that this value has been 80 on average for 8 years (1980–1987), whereas a rate of 100 is usually considered normal. Fortunately, such budgetary limits do not cast doubt on the overall preventive maintenance policy; because the implemented strategy is relatively far from the reference damage (Figure 1), it is possible to accept a little delay in necessary maintenance. Vigilance should, however, be the watchword. Even small delays have repercussions in the future; if, for example, necessary structural work is put off for 2 years the thickness of the later works will have to be increased by 50 percent. In the worst cases, too long a delay means that there will have to be a radical change of strategy from rehabilitation to simple maintenance.

One major difficulty of a preventive maintenance policy is that users, and so also public powers, have difficulty realizing what is at stake because pavements always appear to be in good condition.

Progressive Construction

In some cases a policy of progressive construction can be better than preventive maintenance. Three real-life cases will be used to illustrate the advantages and disadvantages of these two kinds of strategy—the "Progressive Construction" strategy and the "Structure Catalogue" (French reference document for design of new pavements on national roads) strategy. Economic results will be given for both overall construction and maintenance, and comparisons will be made for 10- and 25-year periods. This case study is taken from the conference on La Route et l'Energie that was held in Paris in 1981.

Strategy 1: Progressive Construction

The progressive construction case is based on an actual case that is analyzed from various points of view including traffic, structure, materials, and maintenance carried out. A plausible scenario can thus be extrapolated over the first 25 years: The initial works are those that have actually been carried out, and the following ones are the result of a calculation based on average hypotheses drawn from available information. Works that will really be carried out in the future could be different depending on unknown factors (quality of materials and implementation quality).

Strategy 2: Structure Catalogue

This strategy is of the Catalogue type with slag-treated gravel base and subgrade. Average maintenance sequences were defined to take into account the increased traffic rates that differ noticeably from those defined in the Catalogue.

Costs, expressed as relative values, are actualized costs under 1981 economic conditions. Thicknesses are expressed in centimeters.

Example 1 This example, selected from the national network, corresponds to a flexible structure made of untreated gravel on medium-quality subgrade. When this road was opened in 1966, traffic was very light (60 HGVs/day), but it grew at an annual geometric rate of 12 percent. The structure had to be rehabilitated (Table 3).

The progressive strategy requires rehabilitation after 14 years and is the most cost-effective; it makes it possible to save 18 percent over 10 years and 10 percent over 25 years compared with the Catalogue strategy.

Example 2 This example is of a motorway that had a light bituminous coating on an exceptionally good base of natural, clean, very thick, well-graded aggregate.

Traffic was always heavy (300 HGVs at the opening in 1965) and had a high growth rate (14 percent geometric per year). In calculating future growth, a lower rate was used to take into account transfer of traffic to the adjoining lane. These circumstances of exceptionally good base plus high traffic flow growth very much favor progressive work (Table 4).

The progressive strategy produces a saving of 21 percent over 10 years and 19 percent over 25 years compared with the Catalogue strategy.

Example 3 This example was also chosen on a motorway that had a bituminous treated gravel structure. General features here were less favorable to progressive working because the soil was only mediocre, although the traffic growth rate

TABLE 3 EXAMPLE 1

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	40 NTG + 9 BC	38 SG + 6 BC
Maintenance	5 BC at 5 years *	5 BC at 5 years
	4 BC at 9 years *	4.8 BC at 14 years
	8 BC + 12 BG at 14 years *	5.6 BC at 21 years
	4.8 BC at 22 years	5.6 BC at 28 years
	5.6 BC at 30 years	

* these interventions were actually carried out.
BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel ; NTG = Non treated gravel.

Analysis after 10 years

	Strategy 2	Strategy 3
Construction cost	0.74	1.1
Updated construction + maintenance cost	1.0	1.22

Analysis after 25 years

	Strategy 2	Strategy 3
Construction cost	0.64	0.95
Updated construction + maintenance cost	1.0	1.11

was less than in the other cases (9 percent). At the opening in late 1972 there were about 220 HGVs per day (Table 5).

The traffic flow growth rate is less than in the other cases, although it is higher than the average for national roads.

The progressive strategy makes possible savings of 8 percent over 10 years and 4 percent over 25 years compared with the Catalogue strategy.

Conclusions Drawn from Examples

It can be seen from this synthetic study that the advantages of a progressive construction method compared with a Catalogue strategy take on even more importance when

- The subsoil has good carrying qualities,
- Initial traffic flow is low,
- HGV traffic growth is high,
- The updating rate is high, and
- Bituminous mixtures are inexpensive.

However, a progressive strategy has two disadvantages:

- More materials, and therefore more energy, are used in the long term. This high energy consumption is further increased by the use of techniques that require bitumen.
- Delays in applying scheduled maintenance courses are less well tolerated.

Moreover, in all cases, progressive construction of structures implies frost damage checking, and some French regions are subject to such deep frosts that the progressive method is ruled out. Thus it can be said that the rigorous climate of many French regions and main-road traffic characteristics (high initial level followed by relatively slow growth) discourage the choice of a progressive strategy. On the basis of all of the elements described, the strengthening (or Catalogue) strategy with preventive maintenance was chosen as the most suitable for France.

Frost Protection

The immediate and lasting frost protection given by a rehabilitation strategy followed by preventive maintenance leads to considerable economic savings.

One of the main advantages of the strategy applied to the French national network is that it has enabled pavements to resist extreme climatic conditions, in particular freeze-thaw cycles, without damage.

Combined rehabilitations were described earlier, and it was mentioned that around 6000 km remain to be treated. This means that HGV traffic has to be limited over part of these roads under thaw conditions.

The extreme conditions of the winter of 1984–1985 underscored this Achilles' heel. Weight limits during the thaw had to be imposed for 2 or 3 weeks on national roads that

TABLE 4 EXAMPLE 2

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	20 BC	38 SG + 8 BC
Maintenance	5 BC at 4 years * 4 BC at 15 years * 12 BC at 21 years * 4 BC at 29 years	4.8 BC at 8 years then, 5.6 BC each year

* these interventions were actually carried out.
BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel.

Analysis after 10 years

	Strategy 2	Strategy 3
Construction cost	0.83	1.16
Updated construction + maintenance cost	1.0	1.27

Analysis after 25 years

	Strategy 2	Strategy 3
Construction cost	0.77	1.06
Updated construction + maintenance cost	1.0	1.23

had not yet been rehabilitated, as well as on the majority of secondary roads. Losses due to reduced turnover and increased costs resulting from reorganized journeys, production, and sales have been estimated at 30 billion francs (around $5 billion).

These losses and additional costs were not incurred only on national roads; secondary roads also play a vital role in end-of-trip deliveries. Nor were these losses a complete write-off for the country. Many of those responsible for road management have no doubt compared this figure with the 2 billion or so francs ($330 million) devoted annually to renovation and preventive maintenance of the national main road network and noted the difference of scale.

The winter of 1984–1985 also demonstrated very clearly the excellent reaction to continuous heavy traffic of the 20 000 km of roads that had received preventive maintenance. It is likely that waterproof qualities of pavements, partially resulting from preventive maintenance, played an important role.

High Levels of Service

High levels of service result in considerable savings by reducing users' costs. The strategy of rehabilitation followed by preventive maintenance also leads to reduced costs for road users, the first of which are the operating costs of vehicles that are especially sensitive to pavement roughness.

In spite of the importance of cost variations that depend on pavement qualities, no precisely quantified figures are available in France. A simple simulation carried out with the World Bank Highway Design and Maintenance Standards (HDM) model nevertheless gives an idea of the scale involved. This simulation estimates the difference between operating costs on a good, even surface and a bad surface at 0.1 franc (or $0.017) per vehicle kilometer. The two evenness values were chosen in the French context and are representative of a newly rehabilitated pavement, or one maintained by preventive maintenance techniques, and a nonrehabilitated pavement subject to curative maintenance.

This difference in operating costs does not tell the whole tale, but extrapolating over the entire national road network of 28 000 km, given traffic flow of 7,800 vehicles daily, gives a yearly total of 8 billion francs ($1.333 billion).

This result should be considered only an indication, but it is likely that savings resulting from reduced vehicle operating costs are approximately 5 times greater than the investment difference between a policy of renovation followed by preventive maintenance and one of curative maintenance.

This review should be completed by adding the time gained

TABLE 5 EXAMPLE 3

	Strategy 2 (carried out)	Strategy 3 (Catalogue) using slag treated gravel
Construction	27 BG + 6 BC	47 SG + 8 BC
Maintenance	7.8 BC every 8 years	4.8 BC at 8 and 16 years 5.6 BC at 24 and 32 years

BC = Bituminous concrete ; SG = Slag treated gravel ; BG = Bituminous treated gravel.

	Analysis after 10 years	
	Strategy 2	Strategy 3
Construction cost	0.85	1.0
Updated construction + maintenance cost	1.0	1.09

	Analysis after 25 years	
	Strategy 2	Strategy 3
Construction cost	0.79	.92
Updated construction + maintenance cost	1.0	1.04

by users. It appears that the level of service provided by preventive maintenance with strengthening is around a significant 10 percent higher than that provided by curative treatment without strengthening, with more or less the same safety levels.

Structural Behavior

Structural behavior results contribute to the evaluation of the French preventive maintenance strategy. These results, established in 1985, were based on statistical analysis of the maintenance carried out since about 1972 and were presented to the 65th Annual Meeting of the Transportation Research Board in 1986.

More than half the preventive maintenance network, in other words 11 000 km of main road network sections, was studied. Three-quarters of these roads were rehabilitated, and the other quarter was new roads.

The main maintenance lessons learned from this study are discussed in the following subsections.

First Maintenance

For all structural types, the first preventive maintenance intervention takes place on average 9 years after the road is opened. The average time is 9 to 10 years for rehabilitated roads and 8 to 9 years for new roads.

These average figures hide considerable variations:

- No maintenance has been carried out on about 5 percent of 16-year-old roads.
- Some sections require early maintenance or two successive interventions. Between 2.5 and 3 percent of stretches are maintained after 3 years or have two interventions in 10 years. These types of problems are studied, and the results are used to modify future design and construction.

The nature and cost of maintenance works vary. The following cost scale has been drawn up for five types of jobs:

Index	*Job*
1	Surface dressing
2.5	3- or 4-cm bituminous concrete
5	5- to 8-cm bituminous concrete
7	9- to 14-cm bituminous concrete
10	Structural rehabilitation (base and wearing courses)

By applying these indices to the percentages of length on which the various types of tasks have been done, it is possible

to obtain an average weighted cost index (AWCI) for the maintenance of each structure.

The value of this weighted index is 3.8 for all structures combined, from 4 to 5 for new roads, and from 3 to 4 for rehabilitated roads. Thanks to the *Technical Guide to Preventive Maintenance*, which gives well-calculated service levels, maintenance decisions are triggered at the right time. This allows relative judgments to be established for various pavements (flexible, semirigid, etc.).

The more HGV traffic there is, the more involved is maintenance, but the analysis shows a ratio factor between these two criteria.

Second Maintenance

Structural behavior results are continuously studied; during the past few years new data, particularly on the second maintenance intervention, have been collected. Figure 3 shows, for all structures, according to their age, the percentage of road stretches that have received first maintenance (solid line) and the percentage of stretches that have received second maintenance (broken line).

At present only the beginning of second maintenance (less than 10 percent of the total length) can be observed between 6 and 12 years. Although this graph's slope variation is less than that of first maintenance, this tendency is still to be confirmed.

In the short term the objective of the permanent monitoring of structural behavior is to contribute to practical preventive maintenance evaluation.

WORK IN PROGRESS

Quantified Service Level Follow-Up

Among the objectives of the preventive maintenance policy practiced on the French national road network is that of maintaining a high level of service to the user. This is why a synthetic system was set up to follow up on level of service. Two priority indicators were selected—one related to journey time and the other to pavement condition.

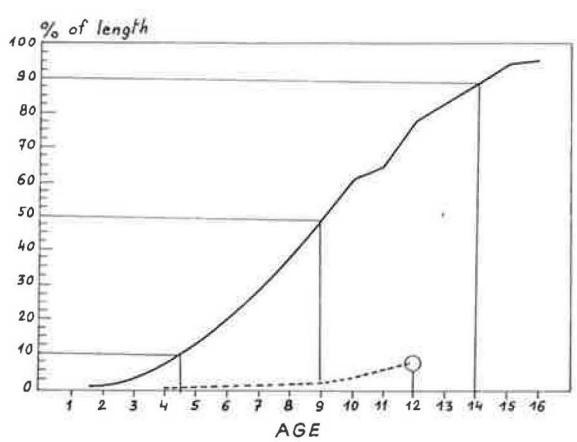

FIGURE 3 Percentage of road stretches that have received first maintenance (solid line) and second maintenance (broken line).

Journey Time Indicator

A method of measuring journey times over a network divided into sections was set up and a working method devised for the measuring teams. Data collection started in 1987.

Pavement Condition Indicator

This is an indicator of both usage wear quality and asset quality. Unlike the journey time indicator, which requires measurements taken on many network sections, it is based on a sample. Sampling methods are currently being set up, and data collection and processing have already started. This indicator should be operational in 1988.

Benefits Derived from Experimental Data

In a country in which all rehabilitated national roads are maintained preventively it is difficult to find an adequate statistical basis for reckoning what a curative maintenance system would cost, but the choice of maintenance policy is directly influenced by the rate of degradation near the end of a structure's life.

Experimental data dictated the fundamental choice of a preventive maintenance policy in the late 1960s and the choices of quantified thresholds in the *Technical Guide to Preventive Maintenance* in 1979. First, a limited number of data were examined closely because there were not many sections that had both suitable structures and a sufficiently long maintenance period for observation.

Initial approximate estimates of pavement degradation evolution laws proved to be reasonably, and sometimes very, accurate. Since that time,

- The Laboratoire Central des Ponts et Chaussées has used a fatigue treadmill to calculate degradation evolution toward the end of the life of roads. The results appear to confirm the first choices, especially for semirigid structures the total fatigue potential of which is used up by dense heavy-vehicle traffic that causes rapid deterioration.
- A few isolated roads that had not received preventive maintenance in time required more costly maintenance or even rehabilitation at a cost considerably higher than that of the preventive alternative.

These considerations, along with a variety of other factors such as the desire of users to have a long-term high service level, have tended to confirm the French engineers and decision makers in their choice of preventive maintenance, which is especially important when the roads in question are subject to heavy traffic.

Recent World Bank analytical documents, although not applicable in the same context, contain solid economic analyses that indicate that delaying road maintenance for too long causes loss of invested capital and increased users costs.

The exchange between countries of information on experimental laws of pavement deterioration evolution, with or without preventive maintenance, is a key factor in determining maintenance policies.

CONCLUSIONS

Having undertaken the renovation of her national roads, France implemented a strategy of preventive maintenance for the network in 1972. This program is today applied to 21 000 km of roads.

Given the density of HGV traffic and the sometimes very severe winters, this strategy is the most effective if a high, consistent level of service is to be ensured both in time and in space.

Control of the preventive maintenance program depends on strict follow-up evaluations of pavement condition, a computerized data bank, and the *Technical Guide to Preventive Maintenance* that allows priorities to be determined.

A preventive maintenance program offers relative flexibility, but takes time and requires long-term funding.

Rehabilitation and preventive maintenance provide frost protection and so produce considerable savings. The vulnerability of the secondary network and a small part of the main network led to turnover losses and additional costs estimated at more than 30 billion francs ($5 billion) in the exceptionally hard winter of 1984–1985.

The average preventive maintenance cost for French national roads is around 36,000 francs per kilometer per year (about $9,600/mi per year). This figure should be compared with the savings of about 300,000 francs per km ($80,000/mi), for the average French traffic volume of 7,800 vehicles per day, attributable to the difference between vehicle operating costs on national roads subject to preventive maintenance and secondary roads under curative maintenance.

The French preventive maintenance program has, for 15 years, represented an important means of developing innovations and contributing to road maintenance techniques.

Statistical analysis of preventive maintenance works over 13 years and 11 000 km has highlighted the good condition of the main road network, thus showing how adequate were the decisions made for the special problems of the country.

The French preventive maintenance policy should be followed in the future with the same determination as in the past. Present results are favorable but provisional and will be enriched by results from studies (such as permanent structure behavior figures) now taking place and the setting up of a service level follow-up system.

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